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Journal
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Yearly Respiration Rate and Estimated Energy Budget for *Sagitta elegans*[1]

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Sameoto, D. D. 1972. Yearly respiration rate and estimated energy budget for *Sagitta elegans*. J. Fish. Res. Bd. Canada 29: 987–996.

The respiration rate of *Sagitta elegans* in Bedford Basin, Nova Scotia, was found to be significantly different at different times of the year. Respiration rates were lower in summer and fall than during spring because the animals acclimated to warmer temperatures as the year progressed. The annual energy expenditure by respiration of the *S. elegans* population in St. Margaret's Bay, Nova Scotia, was equal to the net yearly production of the population; the calculated minimum ingested energy for this population was estimated to be between 13.2 and 20.0 kcal 100^{-3} year^{-1}, or about 0.7–1.1% of the estimated total energy produced annually by copepods in the Bay. *S. elegans* probably has its greatest impact on the zooplankton community in St. Margaret's Bay during winter and early spring, when its biomass is greatest and its energy of respiration per unit volume of water is highest.

Sameoto, D. D. 1972. Yearly respiration rate and estimated energy budget for *Sagitta elegans*. J. Fish. Res. Bd. Canada 29: 987–996.

Le taux respiratoire de *Sagitta elegans* dans le bassin Bedford, Nouvelle-Ecosse, varie selon les saisons. Il est plus bas en été et en automne qu'au printemps, parce que les organismes s'acclimatent à des températures qui vont en augmentant à mesure que l'année s'avance. La dépense annuelle d'énergie due à la respiration de la population de *S. elegans* dans la baie St. Margaret, Nouvelle-Ecosse, est égale à la production annuelle nette de la population; le minimum d'énergie absorbée par cette population a été estimé entre 13.2 et 20.0 kcal 100^{-3} an,$^{-1}$ ou environ 0.7 à 1.1% de l'estimé de l'énergie totale produite annuellement dans la baie par les copépodes. *S. elegans* exerce probablement sa plus grande influence sur le zooplancton de la baie St. Margaret en hiver et au début du printemps, quand sa biomasse et son énergie respiratoire par unité de volume d'eau sont à leur maximum.

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[1] Bedford Institute Contribution.

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Reeve (1968) reviewed 11 studies on macrozooplankton and concluded that chaetognaths represented 22% of the biomass of zooplankton in the North Atlantic. He estimated that for the oceans as a whole the biomass of chaetognaths was about 30% of that of copepods and concluded that they are the primary carnivores in the marine environment and therefore extremely important in the food chain. These conclusions have been supported by recent studies on macrozooplankton on the Atlantic coast of Nova Scotia (Sameoto 1971, MS 1971). *Sagitta elegans* was found to be the most important invertebrate planktonic predator with respect to numbers and biomass in St. Margaret's Bay and Bedford Basin, N.S. In both localities its biomass exceeded that of copepods during the winter and early spring months. However, little is known about the energy requirements of *S. elegans*, and estimates of its predatory impact on the zooplankton community have therefore been speculative.

Energy requirements of an organism may be determined directly by feeding experiments that measure the consumption and assimilation rates, an approach followed by Reeve (1968) with *S. hispida*, a tropical species. This procedure has been unsuccessful with *S. elegans*, owing to difficulty in getting the animal to feed in the laboratory. A second approach is the indirect method of calculating the amount of ingested energy from respiration rates of the population and estimates of growth.

In the energy equation

$$C = P+R+F+U,$$

C = food consumed, P = production, R = respiration, F = feces, and U = excretion (Edmondson and Winberg 1971). Population production was calculated for a population in St. Margaret's Bay, N.S., population respiration was determined by laboratory experiments conducted at a range of body sizes and temperatures throughout the year, and C was estimated by applying assimilation efficiencies derived from the literature.

Methods

Sagitta elegans was collected in Bedford Basin, an area about 12 miles from St. Margaret's Bay (Fig. 1). Animals were collected with a #6 (243 μ mesh) ¾-m plankton net having a large plastic bag attached to the end of the net, into which the animals settled. The plankton tows were made vertically from a depth of 50 m to the surface. The animals were taken directly from the net and placed in an insulated container, which held seawater at the temperature of the basin at 30 m depth.

In the laboratory the animals were placed in 35-ml glass-stoppered bottles containing seawater that had been

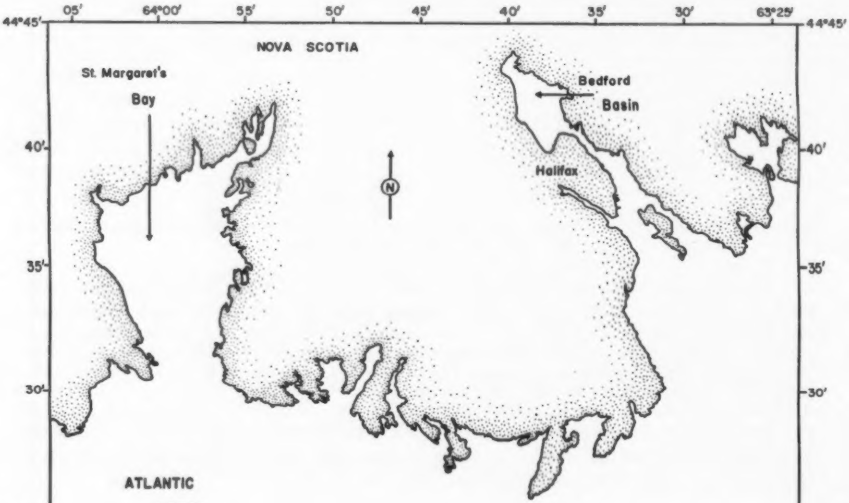

Fig. 1. Location of St. Margaret's Bay and Bedford Basin.

vacuum-filtered through a 3-μ millipore filter. No antibacterial agents were added to the water. It was assumed that bacterial growth would be the same in the control and experimental bottles. The bottles were flushed with 70 ml of filtered sea water at the experimental temperature. The stoppered bottles were placed in a water bath with temperature control of ± 0.25 C. The first bottle and every fifth bottle was a control that did not contain an animal. After 24 hr, the bottles were removed from the bath, the water was siphoned into 29-ml glass-stoppered bottles, and the animals were blotted on filter paper and weighed to the nearest .01 mg. The animals were collected and placed in bottles in the water bath in less than 1 hr.

The oxygen concentration was determined after 24 hr by the Winkler method (Strickland and Parsons 1968).

Animals from each plankton sample were tested at two temperatures in each experiment. These were the highest and lowest temperatures recorded in the basin at the time of collection, and represented the range of temperature the animals would experience within a 24-hr period, because *S. elegans* is a diurnally migrating species that spends daylight hours in deep water and migrates to the upper layers to feed during the night (Alvariño 1965; Paerre MS 1970; Sameoto 1971).

A temperature of 4 C was always found at some deep level in the basin from early May to the middle of February (Fig. 2). Therefore, this temperature was included in all the experiments during the period it was found in the basin. The changing respiration rates with time at 4 C provided evidence for the process of acclimation to different temperature regimes.

The data from each experiment were tested for nonlinearity by testing the significance of the second regression coefficient in a fitted parabola (Bliss 1970), only the data for 10 C ($F = 4.01$; df = 1 and 47, $P < 0.05$) showed a significant curvilinear trend. In order to obtain a value for the regression coefficient of Q_{O_2} on weight comparable to those given in the literature, respiration rate and body weight data from each experiment were fitted to a power curve ($Y = aX^b$) by the least squares method.

The linearity of the data was probably due to the narrow range of body weights tested. In all probability the regression curves would have been curvilinear had the method been sensitive enough to test animals less than 0.5 mg (≈ 5 mm in length).

Results

The respiration rate of *S. elegans* increased as the water temperature increased in the spring and early summer (Fig. 3–6). The higher rates were due largely to increases in the slopes of the regression lines rather than to increases in the Y intercept (Fig. 4, 5). The dates, the water temperature of the experiments, the calculated power curve regression equations, and correlation coefficients for linear regression and power curves are given in Table 1. No significant difference was found between the correlation coefficients calculated by the two methods of regression analysis.

All possible paired combinations of the respiration regression lines were compared using an analysis of covariance with multiple covariates program (Dixon 1968). Considering the respiration at 4 C (Table 1, Fig. 6) there was a lower regression on each succeeding date from June 15 to October 14, suggesting acclimation to rising temperatures, after which respiration levels began to rise. However, the differences on dates from August 26 to February 13 were not statistically significant, and the level on August 3 was not significantly different from that on February 13.

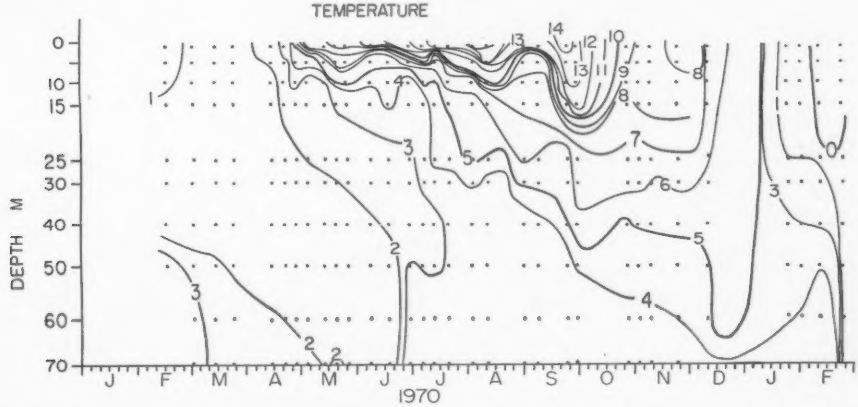

FIG. 2. Seasonal temperature structure for Bedford Basin. Data partially obtained from Platt and Irwin (MS 1971).

ESTIMATED ENERGY OF RESPIRATION FOR *S. ELEGANS* IN ST. MARGARET'S BAY

The energy used in respiration by the St. Margaret's Bay *S. elegans* population during 1969–70 was estimated using the respiration equations calculated from the Bedford Basin population of *S. elegans*. The frequency data for each length class of 1 mm for the St. Margaret's Bay population through the year was taken from Sameoto (1971). The number of μ liters of O_2 used by all the animals in each size class in the sample was calculated by converting the length into mg of live weight (Sameoto 1971), then using the respiration equation (Table 1) that corre-

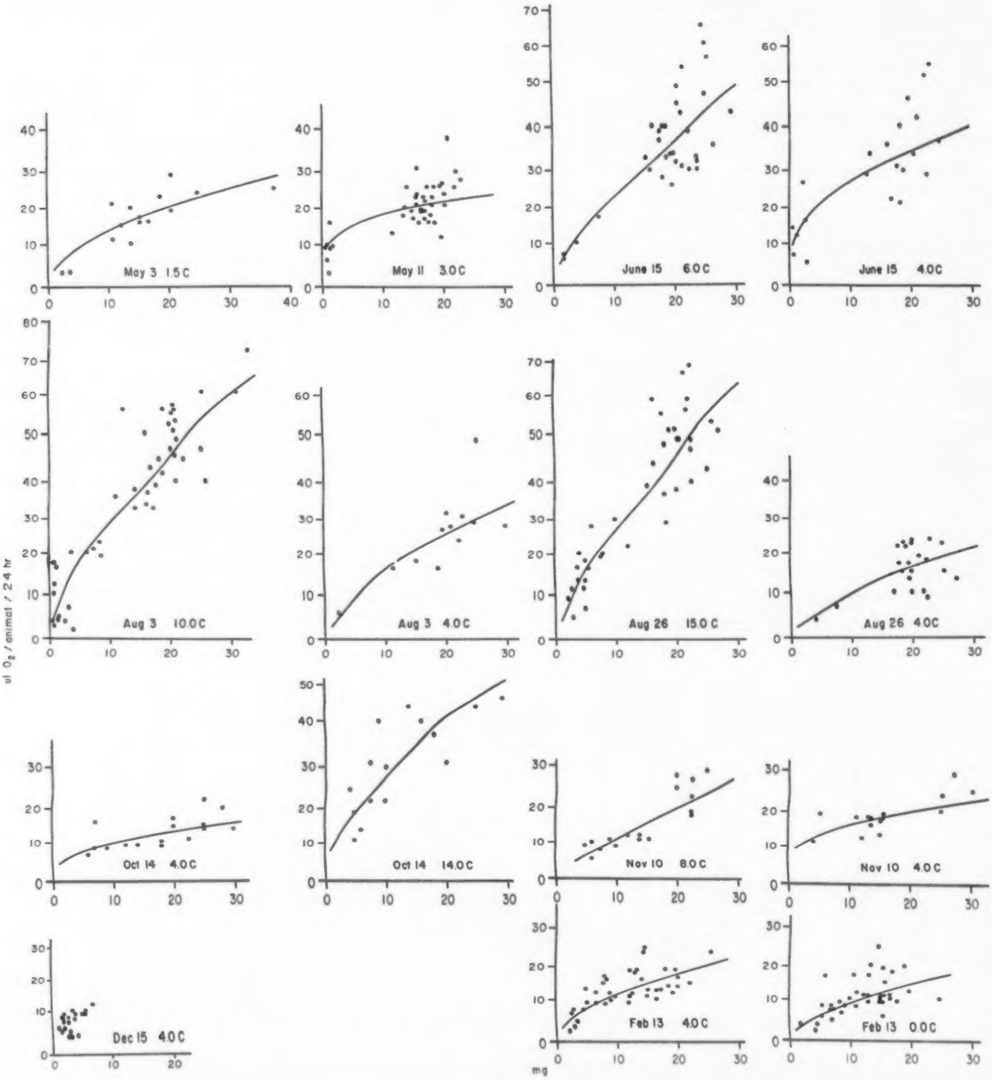

FIG. 3. Data points for oxygen consumption versus live body weight of *S. elegans* for respiration rate experiments at different temperatures and dates. Regression lines are calculated power curves ($Y = aX^b$).

sponded to the same time of year and water temperature. These values were added, then divided by the total number of animals in the histogram to give a mean respiration rate for one animal on that date. The mean animal weight was divided into the live biomass on the same date (Sameoto 1971) to give an estimate of the total number of animals over 4 mm length in the population in 100 m³ of water. Animals less than 4 mm were not included in Sameoto's histograms. The number of animals was multiplied by the

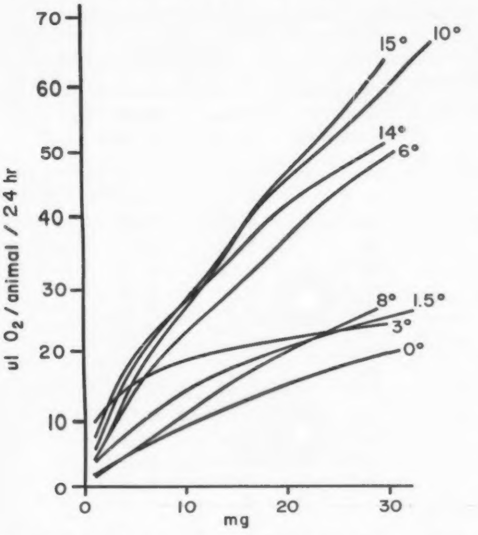

FIG. 4. Comparison of regression lines for respiration rate for temperatures from 0 to 15 C excluding experiments at 4.0 C.

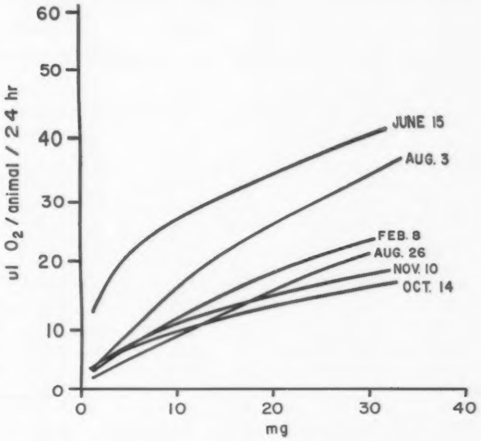

FIG. 5. Comparison of regression lines for respiration experiments conducted at 4.0 C throughout the year.

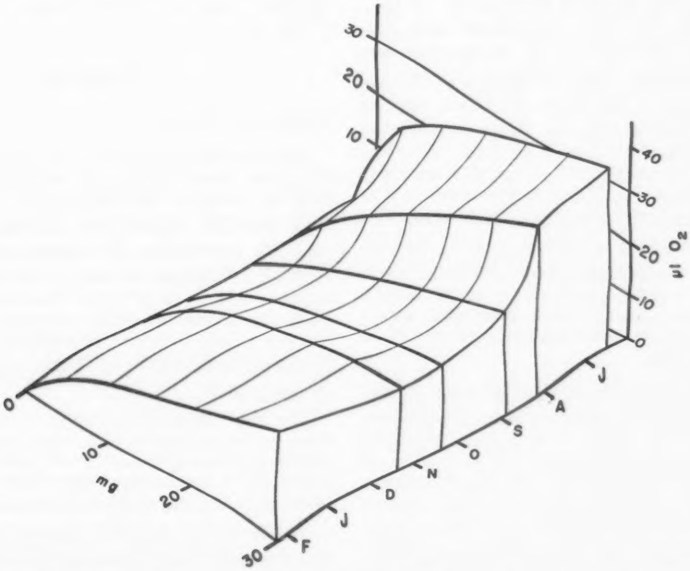

FIG. 6. Three dimensional diagram showing the changes in respiration rate of *S. elegans* at 4 C from May to February.

TABLE 1. Experimental temperatures and regression equations for oxygen consumption during 24 hr versus live body weight of *S. elegans*, the respiration rate per hour for 1 g of live animals all equalling 20 mg body weight and correlation coefficient for the power curve and linear regression for each group of data.

Date	Temp.	Equation	μliters O_2/g wet wt/hr (20 *mg* animals)	Correlation coefficient	
				Power curve	Linear regression
May 3/70	1.5	$Y=3.67x^{.56}$	40.8	0.53	0.61
May 11	3.0	$Y=8.32x^{.32}$	45.2	0.66	0.80
June 15	6.0	$Y=4.40x^{.71}$	76.9	0.92	0.71
June 15	4.0	$Y=11.94x^{.34}$	70.0	0.76	0.78
Aug. 3	10.0	$Y=5.85x^{.68}$	93.3	0.87	0.89
Aug. 3	4.0	$Y=3.09x^{.71}$	53.9	0.90	0.94
Aug. 26	15.0	$Y=4.36x^{.79}$	96.9	0.92	0.86
Aug. 26	4.0	$Y=1.50x^{.77}$	31.2	0.66	0.37
Oct. 14	14.0	$Y=7.56x^{.57}$	86.9	0.70	0.63
Oct. 14	4.0	$Y=3.44x^{.45}$	27.5	0.66	0.53
Nov. 10	8.0	$Y=1.55x^{.85}$	41.2	0.89	0.78
Nov. 10	4.0	$Y=3.82x^{.45}$	30.6	0.68	0.78
Feb. 13/71	4.0	$Y=2.61x^{.69}$	36.9	0.56	0.59
Feb. 13	0.0	$Y=1.76x^{.69}$	28.9	0.69	0.52

amount of oxygen used by one animal times 1000 to obtain the number of ml of O_2 used by the population in 24 hr. This value was converted to calories by an oxycalorific equivalent of 4.8 (Table 2).

St. Margaret's Bay was unstratified from December to May and a constant temperature was applied to all depths. From June to October the mean temperature of the upper 20 m was applied to immature animals and the mean temperature below 20 m (Sharaf El Din et al. MS 1970) was applied to the mature animals, since this accorded with their distribution. These temperatures determined which respiration equation was used. The energy of respiration and the mean body weights of the immature and mature animals were determined separately. The number of calories used by the two groups were then added to obtain the total energy used in respiration by the population (Table 2) on that particular date.

The estimated numbers of calories used in respiration by the population were plotted for the year from December 12, 1969 to December 12, 1970. The area under the curve was used to give an estimate of the total energy of respiration for the population during the year. This was found to be 4.9 kcal 100 m^{-3} $year^{-1}$ or 2.45 kcal m^{-2} $year^{-1}$, an amount greater than 4.6 kcal 100 m^{-3}, the total energy produced in the yearly net production of *S. elegans* (Sameoto 1971).

The *S. elegans* population in St. Margaret's Bay used the maximum amount of energy for respiration during the winter and early spring months, and the least amount during August and September (Table 2).

Discussion

METABOLIC RATES

The respiration experiments demonstrated that *S. elegans* has the ability to acclimate its metabolic rate to minimize changes in its respiration rate with seasonal temperature changes. Acclimation probably occurred at all temperatures and not only at 4.0 C. Evidence for this is the fact that the regression line at 8.0 C on November 10 was significantly lower than the regression line for 6.0 on June 15 and the regression line at 10 C on August 3 was not significantly different from that for 15 C on August 26.

The high respiration rates at 15, 14, 10, and 6 C were found at times when these temperatures were confined to the upper 10 m of water and the water below 10 m was much colder. These high rates may have been the result of the animals not being acclimated to the warmer temperatures since the majority of *S. elegans* are usually found in the colder water below 10 m. If the rates for water temperatures below 10 m, a range of 0–13 C for the year, are considered as representing the normal respiration rates during the year, they fall within a relatively narrow range well within the bounds of the respiration regression lines for 4.0 C over the year. The range of respiration rates at 4.0 C for animals weighing 20 mg was from 33.1 to 13.2 µliters O_2 animal^{-1} 24 hr^{-1}. The respiration rate of *S. elegans* weighing 10 mg at 4. 0C on August 26 was 37 µliters O_2 g^{-1} wet weight hr^{-1}. This was similar to the rate of 45.5 µliters O_2 g^{-1} wet weight hr^{-1} for the copepod *Epischura baikalensis* at 4.5 C (Wolvekamp and Waterman 1960).

The respiration rate of *S. elegans* during February when the temperature was as low as 0 C, was significantly lower than rates at other temperatures during the year. This concurred with observations that showed *S. elegans* had a reduced growth rate during February and March (Sameoto 1971).

TABLE 2. Energy used in respiration and calculated total release of amino acids by the *S. elegans* population in St. Margaret's Bay from December 12, 1968 to April 28, 1970.

Date	Depth (*m*)	Temp. (*C*)	Respiration rate equation	Mean body wt (*mg*)	µliters O_2/animal per 24 hr	Live biomass g/100 m^3	Dry biomass g/100 m^3	ml O_2 used by population in 24 hr	Calories used by biomass in 100 m^3 for respiration in 24 hr	
Dec. 12/68	0–50	5.0	$Y=3.82\times^{.45}$	4.4	9.3	1.0	0.08	2.1	10.2	
Jan. 10	”	4.0	$Y=2.61\times^{.64}$	5.2	7.8	2.2	.18	3.3	16.0	
Jan. 23	”	2.0	$Y=2.61\times^{.64}$	7.9	10.6	2.2	.18	2.9	14.3	
Feb. 6	”	2.0	$Y=2.18\times^{.64a}$	6.9	8.9	2.5	.21	3.2	15.6	
Mar. 5	”	1.0	$Y=1.76\times^{.69}$	8.2	9.2	1.5	.12	1.7	8.2	
Apr. 3	”	2.2	$Y=3.67\times^{.56}$	12.7	17.8	2.4	.20	3.4	16.3	
May 3	”	3.0	$Y=8.32\times^{.32}$	14.1	19.4	1.5	.12	2.1	10.0	
May 29	”	3.8	$Y=11.94\times^{.34}$	12.6	28.2	1.0	.08	2.2	10.9	
June 19	0–20	6.0	$Y=4.40\times^{.71}$	2.0	21.7	.08	.01	0.8	4.1	15.7
June 19	20–50	4.0	$Y=11.94\times^{.34}$	12.6	30.0	1.0	.08	2.4	11.6	
July 10	0–20	10	$Y=5.85\times^{.68}$	2.7	23.3	0.4	.03	3.4	16.7	22.3
July 10	20–50	4.0	$Y=3.09\times^{.71}$	11.3	21.8	0.6	.05	1.2	5.6	
July 17	0–20	11.0	$Y=5.85\times^{.68}$	2.5	15.0	0.5	.04	3.0	14.6	18.7
July 17	20–50	5.0	$Y=3.09\times^{.71}$	15.4	21.7	0.6	.05	0.8	4.1	
July 29	0–20		$Y=4.36\times^{.79}$	2.5	11.9	1.1	.09	5.3	25.5	25.9
July 29	20–50	7.0	$Y=3.09\times^{.71b}$	12.6	16.1	.06	.01	0.1	0.4	
Aug. 11	0–20	11.0	$Y=5.85\times^{.68}$	1.8	17.3	0.1	.01	1.0	4.7	4.9
Aug. 11	20–50	4.0	$Y=1.50\times^{.77}$	11.3	10.3	0.05	.001	0.05	0.2	
Sept. 24	0–20	16.0	$Y=4.36\times^{.79}$	2.0	13.5	0.03	.001	0.2	1.0	2.0
Sept. 24	20–50	9.0	$Y=1.55\times^{.85c}$	6.7	10.4	0.1	.01	0.2	1.0	
Oct. 3	0–20	13.0	$Y=7.56\times^{.57}$	2.7	15.3	0.3	.02	1.6	7.7	10.1
Oct. 3	20–50	6.0	$Y=3.44\times^{.45d}$	5.6	8.7	0.3	.02	0.5	2.4	
Oct. 16	0–20	13.0	$Y=7.56\times^{.57}$	2.5	16.7	0.3	.02	2.0	9.8	16.5
Oct. 16	20–50	6.0	$Y=3.44\times^{.45}$	5.4	8.3	0.9	.07	1.4	6.7	
Oct. 24	0–20	9.0	$Y=1.55\times^{.85}$	1.8	5.5	0.5	.04	1.5	7.4	16.2
Oct. 24	20–50	6.0	$Y=3.82\times^{.45}$	3.7	9.6	0.7	.06	1.8	8.8	
Nov. 6	0–50	8.0	$Y=1.55\times^{.85}$	3.4	5.1	1.3	.11	1.9	9.4	
Nov. 26	0–50	8.0	$Y=1.55\times^{.85}$	4.0	8.9	1.4	.12	3.1	15.2	
Dec. 12	0–50	8.0	$Y=1.55\times^{.85}$	6.1	8.0	3.5	.3	4.6	22.2	
Dec. 22	0–50	5.0	$Y=3.82\times^{.45}$	4.4	9.1	2.0	.17	4.1	20.0	
Jan. 14/69	0–50	4.0	$Y=2.61\times^{.64}$	7.4	9.5	5.0	.41	6.4	31.1	
Feb. 13	0–50	1.0	$Y=1.76\times^{.69}$	4.4	8.9	3.0	.25	6.1	29.6	
Mar. 7	0–50	1.0	$Y=1.76\times^{.69}$	6.0	10.0	3.3	.27	5.5	26.7	
Mar. 24	0–50	1.5	$Y=1.76\times^{.69}$	7.6	11.1	5.6	.46	8.1	39.6	
Apr. 24	0–50	2.0	$Y=3.67\times^{.56}$	12.6	16.1	11.7	.97	15.0	72.8	

[a] Average rate between 4.0 and 0.0 C, February 13.

[b] Respiration rate for 4 C, August 3.

[c] Respiration rate for 8.0 C, November 10.

[d] Respiration rate for 4.0 C, October 14.

ESTIMATES OF FOOD INTAKE

Table 3 shows some estimates of the assimilation efficiency, $\frac{P+A}{C}$, of various comparable species; they range from 50 to 98%, with a mean of 72%. Taking this mean figure, the earlier estimate (Sameoto 1971) of $P = 4.6$ kcal 100 m^{-3} $year^{-1}$ and the present estimate of $R = 4.9$ kcal 100 m^{-3}, we have

$$C = (4.6 + 4.9) \times \frac{100}{72} = 13.2 \text{ kcal } 100 \text{ m}^{-3} \text{ year}^{-1}$$

Alternatively, one may use Reeves (1968) calculated gross growth efficiency $\left(\frac{P}{C}\right)$ values for *S. hispida* of 19–50%, with a mean of 34.5%. Then $4.6 \times \frac{100}{34.5} = 13.3$ kcal 100 m^{-3} $year^{-1}$, which is in fair agreement with the previous estimate.

POSSIBLE CORRECTIONS TO METABOLIC RATE AND FOOD INTAKE ESTIMATES

Winberg (1956) suggested that for fish in nature the metabolic rate is probably about twice the routine metabolism in the laboratory. Shushkina (1968), who applied Winberg's assumption to the energy budget of organisms studied by herself and her colleagues, concluded that net growth efficiency $\left(\frac{P}{A}\right)$ ranged from 0.2 to 0.6, and that in populations of mixed age it probably was close to 0.3. This value has implications for the relative magnitudes of P and R, for if

$$\frac{P}{A} = \frac{P}{P+R} = 0.3,$$

then $0.7\,P = 0.3$ R and R = 2.33 P. It was concluded earlier that R as measured in the laboratory for *S. elegans* is approximately equal to P, in which

TABLE 3. Estimated percentage of assimilated energy ingested by aquatic poikilotherm carnivores taken from the literature.

Author	Species of animal	Kind of food	% assimilation
Ivleva 1964	*Actinia equina*	mussel meat	60
Klekovskiy and Shushkina 1966	*Macrocyclops albidus*	*Paramecium*	50 (taken from Welch 1968)
Shushchenya and Klaro 1966	*Menippe mercenaria*	Fish meat	98
Lasker 1966	*Euphausia pacifica*	*Artemia* nauplii	84
Johnson 1966	*Esox lucius*	Minnows	72
Ivlev 1939	*Cyprinus carpio*	Chironomid larvae	74
Paine 1965	*Navanaz enermis*	Opisthobranchs	62

TABLE 4. Estimate production of copepods and *S. elegans* from December 1 to April 1 and estimates % of copepod production consumed by *S. elegans*.

				Production			
	Year	Mean biomass g live wt 100 m^{-3}	Turnover rate	g live wt[a] 100 m^{-3}	dry wt[b] g 100 m^{-3}	kcal[c] 100 m^{-3}	kcal consumed
Copepods	1968	7.6	2.0	15.2	1.52	4.2	
	1969	8.8	2.0	17.6	1.76	4.8	
S. elegans (Sameoto MS 1971)	1968	3.0	2.0	6.0+0.5[d]	0.54	2.5	
	1969	3.0	2.0	6.0+0.5	0.54	2.5	5.0 to 7.5

[a] If turnover rate = 2.

[b] Assume dry wt equal to 10% of live weight (Curl 1961).

[c] Cal/g dry wt = –227 + 152x (% C) (Platt et al. 1969) %C = 38% (Curl 1962).

[d] 0.5 = loss due to leaching in preservative (Sameoto 1971).

case $\frac{P}{P+R} = 0.5$. The results would be brought into line with the views of Winberg and Shushkina if we assumed that metabolism in nature was about twice the level in the respirometer. In this case the energy equation becomes

$$C = (4.6 + 9.8) \times \frac{100}{72} = 20.0 \text{ kcal } 100 \text{ m}^{-3} \text{ year}^{-1}.$$

It is reasonably certain that the true value lies between 13.2 and 20.0 kcal 100 m^{-3} year^{-1}.

S. ELEGANS CONSUMPTION OF COPEPODS

The estimated 3-year average for the primary productivity of St. Margaret's Bay was 190 g C m^{-2} year,$^{-1}$ or 3.0×10^6 cal m^{-2} year^{-1} (Platt 1971). Mann (1972) estimated that seaweeds produced 6.03×10^6 cal/m^2 in the Bay as a whole. The zooplankton in St. Margaret's Bay consists almost entirely of copepods for most of the year. If it is assumed that 10% of the primary productivity energy goes into copepod production, a value that Slobodkin (1970) feels may be approximately correct, the energy available to *S. elegans* as copepods, which are its principal prey, would be 900 kcal m^{-2} year^{-1}. The minimum energy ingested by the *S. elegans* population was estimated to be between 13.2 to 20.0 kcal 100 m^{-3}, or 6.6 to 10.0 kcal m^{-2} year,$^{-1}$ which is 0.7–1.1% of the estimated total energy produced yearly by the copepods. These values suggest that *S. elegans* in St. Margaret's Bay is not an important predator of copepods when the total yearly production of copepods is considered. But the maximum biomass of *S. elegans* is found during the winter and early spring months, a time when the biomass and production of copepods are at their lowest (Sameoto 1971). This is also when the maximum amount of respiration energy is used by the *S. elegans* population. Table 4 gives the estimated production for the copepods and *S. elegans* from December to April for 1968 and 1969. The production of copepods at this time is very low due to the low temperature and the lack of food, and the biomass remained relatively constant from January to April 1 (D. D. Sameoto unpublished data). It was assumed the copepods' turnover rate during these months was 2.0. Table 4 shows that *S. elegans* consumed more kcal than the estimated copepod production during this period. Therefore the most probable source of additional copepods is the offshore waters which are much richer in copepods than the Bay at this time of year (D. D. Sameoto unpublished data). *S. elegans* is by far the most important copepod predator in the Bay at this time of year and therefore likely accounts for the major portion of copepod predation.

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ALVARIÑO, A. 1965. Chaetognaths. Oceanogr. Mar. Biol. Annu. Rev. 3: 115–194.
BLISS, C. I. 1970. Statistics in biology. Vol. 2. McGraw-Hill, New York, N.Y. 639 p.
CURL, H., Jr. 1961. Standing crop of carbon, nitrogen and phosphorus and transfer between trophic levels in continental shelf waters south of New York. Rapp. Proces-Verbaux Reunions Cons. Perma. Int. Explor. Mer 153: 183–189.
1962. Analysis of carbon in marine plankton organisms. J. Mar. Res. 20: 181–188.
DIXON, W. J. 1968. Biomedical computer programs. University of California Press, Calif. 599 p.
EDMONDSON, W. T., AND G. G. WINBERG. 1971. A manual on methods for assessment of secondary productivity in fresh waters. IBP Handb. 17. Blackwell, Oxford. 358 p.
IVLEV, V. S. 1939. Balance of energy of carps. Zool. Zh. 18: 303–318.
IVLEVA, I. V. 1964. Elements in the energy balance of *Actinia*. Tr. Sevastopol Biol. Sta. Im. A. D. Kovalenskogo Akad. Nauk SSSR 15.
JOHNSON, L. 1966. Experimental determination of food consumption of pike, *Esox lucius*, for growth and maintenance. J. Fish. Res. Bd. Canada 23: 1495–1505.
KLEKOWSKI, R. Z., AND E. A. SHUSHKINA. 1966. Erna hrung, Atmung, Wachstum und Energie—Um formung in Macrocyclops al bidus. Verh. Int. Ver. Limnol. 16: 399–418.
LASKER, R. 1966. Feeding, growth, respiration, and carbon utilization of a euphausiid crustacean. J. Fish. Res. Bd. Canada 23: 1291–1317.
MANN, K. H. 1972. Ecological energetics of the seaweed zone in a marine bay on the Atlantic coast of Canada. II Productivity of the seaweeds. Mar. Biol. (N.Y.) (In press)
PAERRE, S. MS 1970. Light responses and feeding behaviour of *Sagitta elegans* Verrill. Ph.D. Thesis. Dalhousie University, Halifax, N.S. 197 p.
PAINE, R. T. 1965. Natural history, limiting factors and energetics of the opistholranch *Navanax enermis*. Ecology 46: 603–619.
PLATT, T. 1971. Annual production of phytoplankton in St. Margaret's Bay. J. Cons. Cons. Perma. Int. Explor. Mer 33: 324–334.
PLATT, T., AND B. IRWIN. MS 1971. Phytoplankton production and nutrients in Bedford Basin, 1969–70. Fish. Res. Board Can. Tech. Rep. 247: 172 p.
REEVE, M. R. 1968. The biology of chaetognaths. I. Quantitative aspects of growth and egg produc-

tion in *Sagitta hispida*, p. 168–189. *In* J. H. Steele [ed.] Marine food chains.

SAMEOTO, D. D. 1971. Life history, ecological production and an empirical mathematical model of the population of *Sagitta elegans* in St. Margaret's Bay, Nova Scotia. J. Fish. Res. Bd. Canada. 28: 971–985.

MS 1971. Macrozooplankton biomass measurements in Bedford Basin, 1969–1971. Fish. Res. Board Can. Tech. Rep. 282: 238 p.

SHARAF EL DIN, S. H., E. M. HASSAN, AND R. W. TRITES. MS 1970. The physical oceanography of St. Margaret's Bay. Fish. Res. Board Can. Tech. Rep. 219: 242 p.

SHUSHCHENYA, L. M., AND R. K. KLARO. 1966. Quantitative patterns of feeding and their connection with energy balance in the commercial crab *Menippe mercenaria* (Say.) In. Issled. Tsent. Am. Mercy. 1: Kiev "Naukeva Dunka."

SHUSHKINA, E. A. 1968. Calculation of copepod production based on metabolic features and the coefficient of the utilization of assimilated food for growth. Oceanology 8: 98–110.

SLOBODKIN, L. B. 1968. Summary of the symposium, p. 537–540. *In* J. H. Steele [ed.] Marine food chains.

STRICKLAND, J. D. H., AND T. R. PARSONS. 1968. A practical handbook of seawater analysis. Fish. Res. Board Can. Bull. 167: 1–711.

WELCH, H. E. 1968. Relationships between assimilation efficiencies and growth efficiencies for aquatic consumers. Ecology 49: 755–759.

WINBERG, G. G. 1956. Rate of metabolism and food requirements of fish. Fish. Res. Bd. Canada Transl. 194: 1–202.

WOLVEKAMP, H. P., AND T. H. WATERMAN. 1960. Respiration, p. 35–100. *In* T. H. Waterman [ed.] The physiology of crustacea. Vol. I. Academic Press, Inc., New York, N.Y.

Food Resource Division Among Northern, Marine, Demersal Fishes

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Tyler, A. V. 1972. Food resource division among northern, marine, demersal fishes. J. Fish. Res. Bd. Canada 29: 997–1003.

The division of food resources among 13 demersal fishes was examined over a 16-month period in an area of Passamaquoddy Bay, New Brunswick. Though over 100 prey species were found in the stomachs of the predators, each predator took only three or four principal prey, and these prey made up 70–99% of the mass of the food for each predator species. Which species that a predator took as principal prey depended on prey body size, whether the prey were nekton, epi-fauna, or in-fauna; and whether or not they had a hard test or shell. Within predator species there was significant heterogeneity in diet related to size of predator individual.

The seasonal predators did not feed as a group on their own set of prey species. Most principal prey species of the seasonal predators were taken simultaneously by one or two of the regulars.

Data were compared with published results from two other northern marine areas. Within Irish Sea, Sea of Okhotsk, and also Passamaquoddy winter and summer communities, only 10–24% of the possible recurrences of principal prey among predators actually occurred, i.e. there was relatively little overlap among diets. Such specialization would have adaptive significance in a food-limited production system.

Tyler, A. V. 1972. Food resource division among northern, marine, demersal fishes. J. Fish. Res. Bd. Canada 29: 997–1003.

Nous avons étudié durant 16 mois la répartition des ressources alimentaires parmi 13 espèces de poissons démersaux de la baie Passamaquoddy, Nouveau-Brunswick. Bien que plus de 100 espèces proies aient été trouvées dans l'estomac des prédateurs, chaque prédateur s'était limité à 3 ou 4 proies principales, constituant 70 à 90 % de la masse de nourriture avalée par chaque espèce prédatrice. L'espèce capturée par un prédateur comme proie principale dépend de la taille de la proie, du biotope de la proie, qui peut faire partie du necton, de l'épifaune ou de l'enfodaune, enfin de la présence ou de l'absence d'une coquille ou d'un test dur. Le régime alimentaire, nettement hétérogène au sein d'une même espèce, est lié à la taille individuelle du prédateur.

Les prédateurs saisonniers ne se nourrissent pas, comme groupe, d'un ensemble de proies qui leur est propre. La plupart des proies principales des prédateurs saisonniers sont en même temps la proie de 1 ou 2 espèces de prédateurs réguliers.

Nous comparons nos résultats à ceux obtenus dans deux autres régions marines septentrionales. Parmi les communautés d'hiver et d'été de la mer d'Irlande, de la mer d'Okhotsk et de la baie Passamaquoddy, de 10 à 24 % seulement de réapparitions possibles de proies principales se sont actuellement matérialisées dans les estomacs des prédateurs. Il y a donc très peu de chevauchement entre les régimes alimentaires. Une spécialisation de cette nature aurait une portée adaptative dans un système de production à nourriture limitée.

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Studies on the natural diets of fishes often emphasize the variety of prey found in stomachs and imply that fishes are generalists. Recent work in freshwater fish communities, however, suggests that fishes have overlapping feeding niches only when food resources are superabundant and that niches are rather discrete when food abundances become reduced (Keast 1965; Nilsson 1967; Zaret and Rand 1971).

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The present study extends the evidence from freshwater systems by examining food-resource partitioning among marine fish species in an area of Passamaquoddy Bay, N.B. There are few published studies in which feeding habits of boreal marine fishes are considered within the perspective of a local fish community. Skalkin (1959) examined the pleuronectids of a northern Pacific locality. Nagabhushanam (1965) treated gadoid fishes from a region near Isle of Man. Richards (1963) dealt mainly with juvenile fishes in Long Island Sound. Each of these authors pointed out that the different species investigated specialized on a portion of the food environment.

In a previous paper I showed that the deepwater community of Passamaquoddy Bay fishes had four components: those species found in summer only, in winter only, in all months, and occasionally (Tyler 1971). The aim of the present study was to determine whether feeding specializations were evident in abundant, demersal fishes of the first three components. Thirteen species were sufficiently abundant for extensive analysis. Species were compared in terms of their major sources of food-energy. Questions arose as to whether fishes present seasonally found new, major sources of food or whether they invaded sources already being used by the species that were present throughout the year. If they found new sources, were these different for the summer and winter seasonals?

Materials and Methods

STATION SAMPLING

Fish were collected by otter trawl on a station 2 miles long (3.2 km) and a mile wide (1.6 km) in Passamaquoddy Bay. Several ½-mile tows were made within a day, at least monthly from March 1965 to June 1966. To avoid collecting fishes feeding over sediments that had been disturbed by the trawl, no two drags were made over the same path within a day.

A survey of the station and surrounding area was made with bottom grab and echo sounder along a grid with ¼-mile (0.4 km) quadrants. The area was 20–30 fathoms deep (38–55 m) with gently sloping bottom. Sediments were entirely brown mud.

Details of sampling data, number of tows made, method of trawling, trawl description, bottom temperature, and salinity may be found elsewhere (Tyler 1971).

FISH SAMPLING

Usually, all fishes caught were measured for length (total length or fork length where the latter was applicable) to the nearest centimeter. Infrequently, especially large numbers of a species were caught. The whole catch was then counted and a representative sample of at least 100 fish was measured.

Samples of 25 fish per 10-cm length group were injected in the coelom with formalin as soon as they were landed on deck. In the laboratory, each prey species in each stomach was weighed wet (±0.01 g). A total of 2323 stomachs contained indentifiable food and were used in the analysis.

Data were processed by computer. Detailed tabulation of data is available from the St. Andrews Biological Station (Tyler MS 1971).

The following references were used in invertebrate identifications: Abbott (1954); Bousfield (1960); Brunel (1960); Einarsson (1945); Morris (1951); Pettibone (1963); and Smith (1964). Fish species nomenclature is after Leim and Scott (1966).

Extra trips were made to collect fishes for length–weight measurements so that food consumption of fishes caught on regular sampling dates could be expressed in terms of grams food per kilograms fish. Length–weight data are given in Kohler et al. (MS 1970). Length–weight relations for pollock (*Pollachius virens*) and little skate (*Raja erinacea*) were taken from Steele (1963) and Richards et al. (1963), respectively.

Results

DIFFERENCES IN DIET RELATED TO PREDATOR SIZE

Data were initially analyzed for differences in diet within species, since it was suspected that large individuals were sometimes taking different prey than were small individuals. The aim of the analysis was to divide each predator into the length strata that would best show up any size-related, feeding heterogeneity. The measurement of feeding tendency was based on presence and absence of a prey species in the predator stomachs. Heterogeneity of occurrence was tested for by using the chi-square statistic. Details of the method have been described and a FORTRAN program is available (Tyler MS 1969).

As an example of the size-related heterogeneities that were found, percentage of white hake with *Pandalus* is plotted in Fig. 1 for 4-cm strata. Maximum heterogeneity for frequency of occurrence of *Pandalus* was found when hake less than 28 cm were tested against hake greater than or equal to 28 cm. There was a rapid change in feeding tendency in the 25–28 cm fish (Fig. 1). Percentage data for another prey species, *Mysis stenolepis*, are also plotted in Fig. 1. Maximum heterogeneity for this prey species occurred between hake less than 26 cm, and greater than or equal to 26 cm. The lengths at which feeding changes occur have been termed

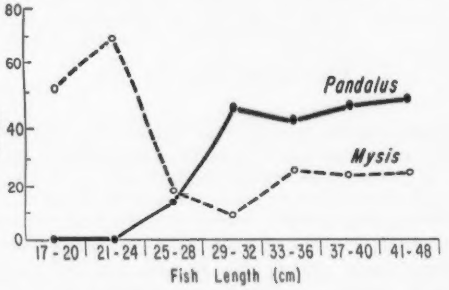

FIG. 1. Percentage of white hake of different lengths that had *Pandalus montagui* and *Mysis stenolepis* in their stomachs.

"threshold lengths" by Parker and Larkin (1959). The two size-groups of predators may be called "feeding stanzas," after terminology by Paloheimo and Dickie (1965). The threshold length for the stanzas was considered to be 27 cm, calculated as the average of the threshold lengths (26 and 28 cm) found for the two prey species.

In addition to *Mysis* and *Pandalus*, *Crangon septemspinosa* and fish remains showed significant heterogeneity by frequency of occurrence between white hake stanzas — the large fish consuming greater percentages of both. These prey items could not be plotted meaningfully in Fig. 1 because they each occurred in fewer than 16 stomachs.

Of the 13 fish species analyzed, two in addition to white hake had feeding heterogeneities associated with length. These species and their stanza length groupings were as follows: thorny skate (*Raja radiata*) 20–39 cm, 40–65 cm; little skate (*Raja erinacea*), 20–44 cm, 45–55 cm.

Generally, smaller fish ate smaller prey (Fig. 2). *Mysis stenolepis* (eaten by small white hake) is smaller bodied than *Crangon septemspinosa* and *Pandalus montagui* (eaten by larger hake). *Erythrops* sp. and *Pleustes panoplus* (eaten by smaller little skate) are smaller bodied than *Meganyctiphanes norvegica*, *Aphrodite hastata*, *Pandalus montagui*, and *Hyas araneus* (eaten by larger little skate). The three amphipod species eaten by small thorny skate (*Maera loveni*, *Leptocheirus pinguis*, and *Unciola leucopis*) are smaller bodied than polychaetes eaten by both thorny skate stanzas (*Nephtys incisa*, *Lumbrineris fragilus*, *Aphrodite hastata*).

MAJOR FOOD-ENERGY SOURCES

Some 100 prey species were found in the fish stomachs during the course of the investigation (Tyler MS 1971). Many of these prey were clearly not major food-energy sources for the fish. Some were found in only a few fish and presumably were consumed by a low percentage of the fish species population. Some prey were found in a high percentage of the individuals of a fish species but in very small quantities. The major food-energy sources were considered to be those prey species which occurred in greater than 10% of a predator species sample at a mean quantity greater than 1 g/kg fish on at least one date during the sampling period.

Though the categorization criteria for major food sources might appear to be too inclusive, only 22 species of the more than 100 prey species fell into the major food source category for the 16 predator species and species stanzas. For convenience, these 22 will be referred to as "principal prey." The species were: the krill, *Meganyctiphanes norvegica;* opossum shrimp, *Mysis stenolepis;* decapod shrimp, *Pandalus montagui*, *Crangon septemspinosa;* toad crab, *Hyas araneus*; amphipods, *Unciola leucopis*, *Maera loveni*, *Leptocheirus pinguis;* polychaetes, *Aphrodite hastata*, *Lumbrineris fragilis*, *Nephtys incisa*, *Praxillella praetermissa;* lamellibranchs, *Yoldia* sp., *Nuculana* sp., *Musculus niger*, *Arctica islandica*, *Venericardia borealis;* brittle star, *Ophiura* sp.; young herring (3–4 cm), *Clupea harengus;*

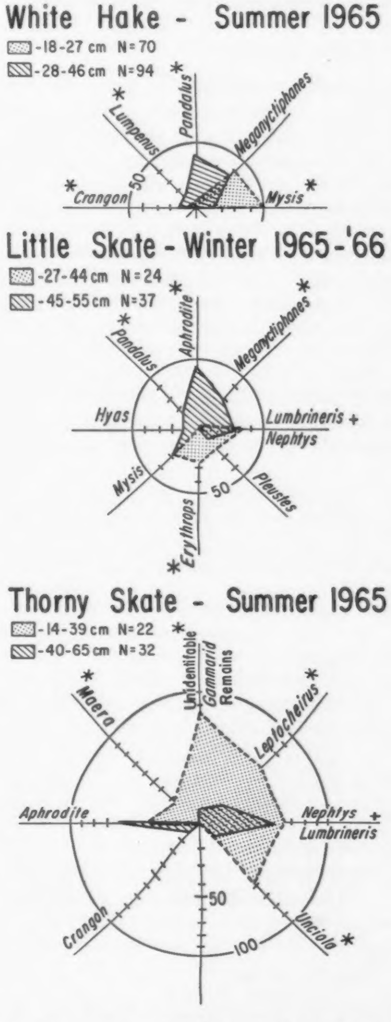

FIG. 2. Percentages of fish in feeding stanzas that contained various prey. Lines between axes connect the percentage points. The asterisk indicates a significant difference ($P = 0.05$) between feeding stanzas.

snake blennies, *Lumpenus lumpretaeformis*, *Lumpenus maculatus*.

As a check on the importance of the principal prey to each predator species, the sum of the weights of the principal prey was expressed as a percentage of the total stomach contents in different seasons (Table 1). Except in four out of 36 cases the principal prey made up 61–99% of the stomach contents (on the average 78%), thus giving substance to the classification of major food energy sources.

FEEDING SPECIALIZATIONS

To facilitate comparison of diets, the fish and their principal prey have been arranged in partition plots in Fig. 3. Predators are arranged so those with most similar diets were adjacent to one another. Generally, the more widely separated in the table the predator species are, the less closely associated they are in their major energy sources.

The median number of principal prey species per predator species was four in summer and three in winter, though there were 20 principal prey utilized by the community in summer and 11 in the winter. The percentage overlap, or re-occurrence of prey in more than one predator species, may be calculated as the empirical number of reoccurrences of prey among predators divided by the number of reoccurrences possible in the partition plot. One reoccurrence means that a prey occurs in two predator species. The total number of reoccurrences possible is calculated as the number of predators minus one multiplied by the number of prey. The percentage reoccurrence of prey in more than one predator group was 24% in winter and 16% in summer. It is clear that the fish were fairly specialized in terms of their major food-energy sources.

Generally, the prey species were divided among the predator groups according to whether they could be caught over, on, or within the sediments (Fig. 3). Two feeding stanzas within a single species usually consumed prey with similar dwelling habits, but of different body size. It will also be noticed that one predator, ocean pout, fed largely on infauna with a hard covering.

FEEDING DISTINCTIONS BY COMMUNITY COMPONENT

In this section, comparisons are made among the diets of the summer, winter, and regular predator groups to find whether invading components had principal prey unique to themselves, whether the winter component fed on prey species abandoned by the summer component, and whether the regulars took the same principal prey in summer and winter.

The summer seasonals did not feed as a group on a unique set of prey species. Thirteen of 20 prey were common to both regular and summer components.

TABLE 1. Percentage by weight of stomach contents comprised by principal prey, and the numbers of stomachs containing food (in parentheses). Dash indicates sample not obtained.

Predators	Mar.–Apr. 1965	May–Nov. 1965	Dec.–Apr. 1965–66	May–June 1966
Regulars				
Atlantic cod	81% (44)	80% (83)	68% (114)	36% (24)
Longhorn sculpin	49% (112)	69% (126)	72% (65)	52% (49)
American plaice	–	87% (90)	67% (72)	90% (97)
Winter flounder	83% (57)	85% (171)	–	77% (129)
Haddock	–	82% (190)	61% (84)	70% (79)
Thorny skate < 40 cm	84% (18)	79% (22)	95% (16)	–
Thorny skate ≥ 40 cm	97% (21)	93% (32)	93% (14)	–
Winter seasonals				
Little skate < 45 cm	22% (8)	–	63% (24)	–
Little skate ≥ 45 cm	94% (21)	–	89% (37)	–
Pollock	–	–	99% (6)	–
Winter skate	–	–	96% (7)	–
Summer seasonals				
White hake < 27 cm	–	94% (97)	–	–
White hake ≥ 27 cm	–	95% (104)	–	–
Silver hake	–	97% (24)	–	–
Fourbeard rockling	–	89% (29)	–	–
Ocean pout	76% (38)	75% (148)	–	77% (71)

Winter Community		American Plaice 20-45 cm	Pollock 15-30 cm	Atlantic Cod 15-40 cm	Longhorn Sculpin 15-35 cm	Little Skate 45-55 cm	Thorny Skate 40-65 cm	Haddock 25-40 cm	Winter Skate 35-85 cm	Thorny Skate 15-39 cm	Little Skate 25-44 cm
Nekton	*Meganyctiphanes*		+	+		+				+	
	Mysis	+	+	+	+					+	
Epi-Fauna	*Pandalus*			+	+	+					
	Hyas				+	+	+				
	Lumpenus					+			+		
In-Fauna	*Aphrodite*				+	+	+	+		+	
	Nephtys					+	+		+		+
	Lumbrineris							+	+	+	+
	Praxillella	+						+		+	
	Unciola										+
	Yoldia	+									

Summer Community		American Plaice 20-45 cm	Atlantic Cod 15-40 cm	Silver Hake 15-30 cm	White Hake 28-45 cm	Longhorn Sculpin 15-35 cm	White Hake 15-27 cm	Fourbeard Rockling 15-30 cm	Thorny Skate 40-65 cm	Thorny Skate 15-39 cm	Winter Flounder 20-40 cm	Haddock 25-40 cm	Ocean Pout 20-65 cm
Nekton	*Meganyctiphanes*	+	+	+	+	+	+	+		+			
	Mysis	+			+		+						
	Clupea	+	+			+							
Epi-Fauna	*Pandalus*		+	+	+	+							+
	Hyas					+							
	Crangon				+								
	Lumpenus				+				+				
In-Fauna	*Leptocheirus*					+	+					+	
	Maera						+	+					
	Unciola						+	+		+			
	Nephtys							+	+	+	+		
	Aphrodite					+			+	+		+	+
	Lumbrineris										+	+	
	Praxillella	+									+	+	+
	Yoldia	+										+	+
	Arctica												+
	Nuculana												+
	Ophiura												+
	Musculus												+
	Venericardia												+

FIG. 3. Principal prey for each feeding stanza. Fishes present throughout the year are enclosed in boxes. Winter flounder were always present but had no food in their stomachs in winter. Plus signs indicate the principal prey of each predator.

Of the remaining seven prey, five were taken by ocean pout alone. Similarly, the winter seasonals did not find a unique set of prey species. Seven out of 11 of the winter community prey were common to members of regular and seasonal components. Two of the major food sources of the winter community, however, belonged only to winter seasonals: *Unciola leucopis* was preyed heavily upon by little skate under 44 cm. Small bottom-dwelling fishes (mainly *Lumpenus*) were eaten by winter skate, and also little skate larger than 44 cm. When the winter seasonals left the area these prey species were exploited by summer seasonals and regulars. When the summer seasonals left the area the seven principal prey unique to them were left unexploited.

The principal prey of the regulars were the same summer and winter except that four additional prey were taken in summer (*Leptocheirus, Unciola, Lumpenus*, and *Clupea*).

Discussion

The question remains as to whether the Passamaquoddy fishes are unusual in their partitioning of major food-resources among themselves. The traditional attitude about northern demersal fishes is that they are trophic generalists. Bigelow and Schroeder (1953) wrote about haddock: "After they take to the bottom they become bottom feeders like cod, devouring all kinds of invertebrates so indiscriminately that, as Baird remarked so long ago, 'a complete list of the animals devoured by the haddock would doubtless include nearly all the species belonging to the fauna'...". Perhaps this generalist interpretation arose because workers were not particularly concerned with questions of whether the bulk of food-energy came from relatively few prey species. Emphasis was placed on the capacity of fish to eat so many different forms. Several workers have shown, however, that northern demersal fishes are not indiscriminate (Jones 1952; Wigley 1956), and that when diets of even related pairs of species are analyzed important differences are born out (Todd 1914; Richards 1963; Kohler and Fitzgerald 1969; Rae 1969).

Data from two assemblages of northern, marine fishes could be directly compared with the results of the present investigation and so were reworked as partition plots. Nagabhushanam (1965) examined stomach contents of gadoid fishes in the Irish Sea near the Isle of Man. All prey species that occurred in more than 10% of the individuals of a predator species are given in Fig. 4. The tendency for the fishes to partition or segregate the food resource is evident. Only 15% of the possible reoccurrences of principal prey among predators actually occurred.

Skalkin's (1959) stomach content data on pleuronectids were based on a sample taken off the Sakhalin coast in the Sea of Okhotsk. Prey species that occurred as 5% of the total weight of the stomach contents of a fish species were listed in the partition plot (Fig. 5). These prey species made up 73 to 92% of the total mass of food in each of four of the five flatfish species that Skalkin studied. In the case of *Lepidopsetta bilineata*, the selected prey species

Isle of Man	*Gadus merlangus* ≤ 22 cm	*Gadus merlangus* > 22 cm	*Gadus esmarki*	*Merluccius merluccius*	*Gadus morhua*	*Gadus minutus*	*Gadus luscus*	*Enchelyopus cimbrius*	*Melanogrammus aeglefinus*
Phasiphaea	+	+							
Meganyctiphanes	+	+	+						
Clupea	+	+		+					
Gadidae		+		+	+				
Cephalopoda				+					
Argentina				+					
Copepoda			+			+			
Crangon		+	+			+	+	+	
Nephrops & Alpheus					+		+		
Calocaris					+	+	+		
Amphipoda						+		+	+
Mysidacea								+	
Lamellibranchia								+	
Ophiuroids									+

FIG. 4. Principal prey for gadid fishes at an Irish Sea locality. Data from Nagabhushanam (1965).

made up 43% of the mass. The fishes clearly had different predation tendencies in terms of principal prey. Only 10% of the possible reoccurrences of principal prey among the five predators actually occurred.

It appears that Passamaquoddy Bay fishes are not unusual in the manner in which they partition major food-sources among themselves. When feeding tendencies of northern marine fishes that have been living together are examined in terms of principal prey, the specializations of these predators become evident. In a food-limited system the more efficient predator would have the greater rations. It is difficult to imagine how such efficiency specializations could evolve if prey species were superabundant and all individuals could get all the rations they could metabolize without evolving prey-specific efficiencies. It is likely that these assemblages of fishes have evolved as part of a competitive, food-limited, production system.

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Il'insk Bank	*Lepidopsetta bilineata*	*Limanda aspera*	*Platessa quadrituberculta*	*Limanda herzensteini*	*Limanda punctatissma*
Glycera capitata	+				
Lumbrineris fragilis	+				
Amphareta acutifrons	+	+			
Terebellidae	+	+	+		
Maldanidae		+			
Mactra		+	+		
Stylariodes plumosa			+		
Serripes groenlandicus			+		
Yoldia johanni			+		
Macoma				+	
Protomedia grandimana				+	+
Ampelisca macrocephala					+
Mysidacea					+

FIG. 5. Principal prey for pleuronectid fishes at a locality in the Sea of Okhotsk. Data from Skalkin (1959).

ABBOTT, R. T. 1954. American seashells. VanNostrand, Toronto, Ont. 541 p.

BIGELOW, H. B., AND W. C. SCHROEDER. 1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv. Fish. Bull. 74: 577 p.

BOUSFIELD, E. L. 1960. Canadian Atlantic seashells. National Museum of Canada, Ottawa, Ont. 72 p.

BRUNEL, P. 1960. Artificial key to the Mysidacea of the Canadian Atlantic Continental Shelf. Can. J. Zool. 38: 851–855.

EINARSSON, H. 1945. Euphausiacea. Dana Rep. Carlsberg Found. 5: 1–183.

JONES, N. S. 1952. The bottom fauna and food of flatfish off the Cumberland coast. J. Anim. Ecol. 21: 182–205.

Keast, A. 1965. Resource subdivision amongst cohabiting fish species in a bay, Lake Opinicon, Ontario. Great Lakes Res. Div. Univ. Mich. Publ. 13: 106–132.

Kohler, A. C., and D. N. Fitzgerald. 1969. Comparisons of food of cod and haddock in the Gulf of St. Lawrence and on the Nova Scotian Banks. J. Fish. Res. Bd. Canada 26: 1273–1287.

Kohler, A. C., D. N. Fitzgerald, R. G. Halliday, J. S. Scott, and A. V. Tyler. MS 1970. Length-weight relationships of marine fishes of the Canadian Atlantic region. Fish. Res. Board Can. Tech. Rep. 164: 211 p.

Leim, A. H., and W. B. Scott. 1966. Fishes of the Atlantic coast of Canada. Fish. Res. Board Can. Bull. 155: 485 p.

Morris, P. A. 1951. A field guide to the shells. Houghton Mifflin, Boston, Mass. 236 p.

Nagabhushanam, A. R. 1965. On the biology of the commoner gadoids in Manx waters. J. Mar. Biol. Ass. U.K. 45: 615–657.

Nilsson, N.-A. 1967. Interactive segregation between fish species, p. 295–313. In S. D. Gerking [ed.] The biological basis of freshwater fish production. Wiley, New York, N.Y.

Paloheimo, J. E., and L. M. Dickie. 1965. Food and growth of fishes. I. A growth curve derived from experimental data. J. Fish. Res. Bd. Canada 22: 521–542.

Parker, R. R., and P. A. Larkin. 1959. A concept of growth in fishes. J. Fish. Res. Bd. Canada 16: 721–745.

Pettibone, M. H. 1963. Marine polychaete worms of the New England region. I. Aphroditidae through Trochochaetidae. U.S. Nat. Mus. Smithson. Inst. Bull. 227: 356 p.

Rae, B. B. 1969. The food of the witch. Mar. Res. Dep. Agr. Fish. Scot. 2: 32 p.

Richards, S. W. 1963. The demersal fish population of Long Island Sound. III. Food of the juveniles from a sand-shell locality. Bull. Bingham Oceanogr. Collect. Yale Univ. 18: 32–72.

Richards, S. W., D. Merriman, Y. H. Olsen, and L. H. Calhoun. 1963. Studies on the marine resources of southern New England. IV. The biology of the little skate, *Raja erinacea* Mitchell. Bull. Bingham Oceanogr. Collect. Yale Univ. 18: 1–97.

Skalkin, V. A. 1959. Food and food interrelationships of flounders of the Il'insk Bank. Izv. Tikhookean. Nauch.-Issled. Inst. Ryb. Khoz. Okeanogr. 47: 62–75. (Fish. Res. Board Can. Transl. 789.)

Smith, R. I. 1964. Keys to the marine invertebrates of the Woods Hole region. Syst.- Ecol. Program, Mar. Biol. Lab., Woods Hole, Mass. 11: 208 p.

Steele, D. H. 1963. Pollock (*Pollachius virens*) in the Bay of Fundy. J. Fish. Res. Bd. Canada 20: 1267–1314.

Todd, R. A. 1914. The food of the plaice. Fish. Invest. Min. Agr. Fish. Food (Gt. Brit.) Ser. II Salmon Freshwater Fish. 2: 31 p.

Tyler, A. V. MS 1969. Computer programs for analysis of feeding heterogeneities related to predator body size. Fish. Res. Board Can. Tech. Rep. 121: 48 p.

1971. Periodic and resident components in communities of Atlantic fishes. J. Fish. Res. Bd. Canada 28: 935–946.

MS 1971. Monthly changes in stomach contents of demersal fishes in Passamaquoddy Bay, N.B. Fish. Res. Board Can. Tech. Rep. 288: 119 p.

Wigley, R. L. 1956. Food habits of Georges Bank haddock. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. 165: 26 p.

Zaret, T. H., and A. S. Rand. 1971. Competition in tropical stream fishes: support for the competitive exclusion principle. Ecology 52: 336–342.

Survival of Hatchery-Reared Rainbow Trout (*Salmo gairdneri*) in Relation to Stamina Tunnel Ratings

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Horak, D. L. 1972. Survival of hatchery-reared rainbow trout (*Salmo gairdneri*) in relation to stamina tunnel ratings. J. Fish. Res. Bd. Canada 29: 1005–1009.

No conclusive evidence was found in tests from 1966 to 1969 in either lentic or lotic environments to support the hypothesis that hatchery-reared rainbow trout (*Salmo gairdneri*) with a high-stamina index had a higher survival potential than those whose stamina index was low. Physical stamina was measured by determining the length of time each fish could withstand sustained swimming in a specially constructed stamina tunnel. For high-stamina rating, fish swam in the tunnel for 80 min; for low stamina, 1–10 min.

In tests of reproducibility of stamina ratings, improved swimming ability of low-stamina fish was demonstrated upon retesting in the tunnel. In 1970, with retested fish, still no evidence was found to indicate higher survival of fish rated as high in stamina. Additional studies are needed to determine if performance of hatchery-reared salmonids in a stamina tunnel is a valid indicator of their survival potential in the wild.

Horak, D. L. 1972. Survival of hatchery-reared rainbow trout (*Salmo gairdneri*) in relation to stamina tunnel ratings. J. Fish. Res. Bd. Canada 29: 1005–1009.

Des essais effectués de 1966 à 1969 en milieu lentique aussi bien que lotique n'ont pas réussi à confirmer l'hypothèse que les truites arc-en-ciel (*Salmo gairdneri*) élevées en pisciculture et possédant un indice de résistance élevé ont plus de chances de survie que les truites à indice faible. Le temps pendant lequel un poisson maintient une nage constante dans un tunnel d'endurance a servi de critère de résistance physique. Une nage de 80 minutes dans le tunnel valait au poisson la note "haute résistance"; une nage de 1 à 10 minutes, la note "faible résistance."

Au cours d'essais répétés, les poissons à faible résistance ont démontré qu'ils pouvaient améliorer leur classement lorsque placés de nouveau dans le tunnel. Il n'a pas été davantage possible en 1970, même avec des poissons réexposés au tunnel d'endurance, de démontrer un taux de survie plus élevé chez les poissons à haute résistance. Il faudra poursuivre des études supplémentaires en vue de déterminer si la performance dans un tunnel d'endurance est, pour les salmonoïdes élevés en pisciculture, un critère valide des chances de survie dans la nature.

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Though there has been much research on evaluating survival of hatchery-reared trout, no quantitative measure has been reported for predicting survival of hatchery fish in the wild. One recent approach to quantifying survival potential of a fish is to measure its physical stamina in terms of swimming duration in a current of fixed velocity. Stamina ratings were assigned to 5567 trout during 1967-70 prior to stocking.

The objective of this study was to determine if high-stamina ratings of hatchery trout in stamina tunnel tests were indicative of their subsequent survival potential in lentic and lotic environments.

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Study Areas

Stamina-indexed rainbow trout (*Salmo gairdneri*) were stocked in two lakes and two streams. Parvin Lake is a 25-ha eutrophic reservoir. Rainbow trout and brown trout (*Salmo trutta*) are the principal game fishes in the lake. Detailed physical, chemical, and biological characteristics are well given by Buscemi (1961) and Klein (MS 1967). The lake is surrounded by a fence permitting accurate recording of the stamina fish captured by fishermen. Stamina fish stocked in the lake represented only a small portion of the total regular fish plants, so competition was not increased appreciably.

The Walden Hatchery Pond has a surface area of 0.15 ha and a maximum depth of 1.2 m. A continuous inflow of spring water, approximately 756 liters/sec, provides adequate circulation and oxygen to prevent winter- or summerkill. Rainbow trout are the principal fish present. The large amount of littoral area supports a dense population of aquatic plants (*Potamogeton*, *Ceratophyllum*, and *Myriophyllum*). The pond was closed to public fishing to eliminate unaccountable fish loss. The addition of stamina fish resulted in a purposeful overstocked condition to increase competition.

Hell Creek is a small meandering stream averaging 1.5 m wide with deeply undercut banks. Average depth is 0.5 m and several pools are 1.2 m deep. Stream flows generally range between 184 and 475 liters/sec. Water velocity varies from 0.335 to 1.067 m/sec in the riffles and from 0.122 to 0.366 m/sec in the pools. Brown trout is the principal fish species. Approximately 2.2 km of stream was chosen as the test section. This section is on private land, thus minimizing unaccountable fish loss from angling. Permanent barriers similar to those used by Reimers (1966) were placed at the upper and lower ends to ensure against fish escapement. Fish loss from migration could take place only during the winter months when the barriers were removed because of icing conditions. The stocking of stamina fish resulted in a purposeful overstocked condition to increase competition.

The Michigan River is also a meandering stream but considerably larger than Hell Creek. Average width is approximately 5.9 m. Stream flows range from 700 liters/sec in the fall to 2800 liters/sec during spring runoff. The stream is composed of nearly equal portions of riffle and pool habitat. Brown trout are the most abundant fish. Approximately 4 km of stream were chosen as the test section. Migration out of the test section was possible due to lack of barriers, even though experimental fish were stocked into the middle of the section. Unaccountable fish loss from fishing was minimal since all persons granted fishing privileges limited themselves to brown trout 25 cm or larger. The stocking of stamina fish was assumed to cause some overpopulation and increase competition somewhat.

Materials and Methods

A single strain of fall-spawning rainbow trout with a long history of hatchery domestication was used throughout the study. Fish were reared at the Watson Lake Rearing Unit in 1966 and 1967 and at the Bellvue Research Hatchery from 1968 to 1970. All fish were fed identical dry diets during each year, but formulations varied somewhat between years.

All fish were hand sorted, and trout from 155 to 165 mm in standard length were used in all areas except the Walden Pond, where 142- to 152-mm fish were used. However, in Hell Creek in 1967 a group of 206- to 216-mm fish was also used. All fish were taken off feed 18–24 hr prior to testing in the stamina tunnel.

Stamina was measured in a swimming tunnel similar to the one described by Thomas et al. (1964). This apparatus is a 1500-liter, recirculating, closed-water system which maintains constant temperature and oxygen content. A sample of 48–50 trout was placed in the tunnel for each run. Fish were allowed to adapt to a velocity of 0.076 m/sec for 5 min, and velocity was then increased at timed increments to a maximum of 0.458 m/sec. Trout swam against the current until they became exhausted and were flushed past a bright light, through an electrical field, and out into a collecting chamber.

A performance index for the entire group was calculated as the arithmetic mean of the times (minutes) at which individual fish were flushed out of the testing chamber. Fish were classified as low in stamina if they were flushed out in 1–10 min and as high in stamina if they remained in the tunnel for 80 min. Equal numbers of high- and low-stamina trout from each "stamina run" were retained and the remaining fish discarded. Only trout rated in the stamina tunnel were used for stocking.

For identification after planting, a left paired fin was excised from each low-stamina trout and a right fin from each high-stamina trout. Previous studies (A. E. Thomas personal communication; Horak 1969) showed no significant difference in stamina between fish with right and left fins clipped of a given pair, even though there are numerous reports indicating more serious debilitation from pectoral than from pelvic clips. After marking, fish were weighed and allowed one week of rest before being stocked into the designated study area.

Recovery records from Parvin Lake were largely obtained by checking creels of fishermen as they left the lake, those from the Walden Pond by draining, and those from Hell Creek and the Michigan River by using backpack electrofishing gear. Statistical significance between the returns of high-stamina and low-stamina groups was determined using chi-square tests performed in a 2 × 2 contingency table at $P = 0.05$.

The possibility that high- and low-stamina fish might have different vulnerability to angling was investigated. Information on this point was necessary to interpret data from Parvin Lake, where almost all recoveries of test fish were made by angling. Also, differences in angling vulnerability would bias data from the other study areas, where limited fishing was done. Tests, by fly fishing, were conducted in the Walden Pond in 1968 and 1969 and in the Michigan River in 1969 (Table 1). No significant difference was found between the high- and low-stamina groups.

During 1967–69, an additional 1429 rainbow trout were tested in the stamina tunnel to determine if the indices were reproducible. After a 3- to 7-day rest period, these fish were retested and this performance was compared with the original test.

Due to the low reproducibility of stamina indices in in 1967–69, the testing procedure was modified in 1970. Those fish that were again rated as low in stamina upon testing a second time in the tunnel were retained as the low-low-stamina group, and those that were again rated high as high-high-stamina group. Fish that improved their swimming times to between 11 and 40 min were also retained as a separate group.

Recaptures of Fish Rated Once

At Parvin Lake an apparently greater percentage of low- than high-stamina fish were consistently

TABLE 1. Numbers of high- and low-stamina hatchery rainbow trout caught by fly fishing two areas in 1968 and 1969.

Period of recovery after stocking	Low stamina	High stamina
Walden Pond 1968		
Within 14 days	33	38
In 15–71 days	24	35
In 72–97 days	24	21
Total	81(265)[a]	94(265)
Walden Pond 1969		
Within 14 days	56	48
In 15–71 days	33	35
Total	89(265)	83(265)
Michigan River 1969		
Within 72 days	23	34
In 73–110 days	9	12
Total	32(272)	46(272)

[a] Number of fish stocked.

returned from the 1966 plant, while the reverse was true for the 1967 plant (Table 2). However, in none of these returns was the high-stamina group significantly different from the low-stamina group.

At the Walden Pond, recoveries appeared to favor the high-stamina group for the 1968 plant while the reverse was true for the 1969 plant. Significant differences existed only for recoveries within 14 days for the 1968 plant where the high-stamina group was significantly greater than the low (P = .04). High-stamina fish, then, did appear to have a higher survival during the first 2 weeks after stocking in 1968.

More high- than low-stamina fish were consistently recovered from Hell Creek in both size groups during 1967. However, significant differences were found for only one recovery period. This was the overwinter recovery of the large-size group when 12.8% more high- than low-stamina fish were recaptured (P = .02).

Recoveries in 1968 consistently favored the low- over the high-stamina group but no significant differences were found.

In 1969, recoveries were nearly identical for the two groups.

Recoveries from the Michigan River were low at each sampling because only a small portion of the test section was electrofished. In none of the samplings was there a significant difference between the recoveries of high- and low-stamina fish, nor was there a difference when all recoveries were combined.

TABLE 2. Percentage recoveries during various periods of high- and low-stamina hatchery rainbow trout that were stocked in the four areas in various years (except in the tests at Parvin recaptured fish were returned).

Period of recovery	Low stamina	High stamina
Parvin Lake plant 1966		
1967	34.6	31.3
1968	16.5	11.1
1969	3.8	2.4
Total	54.9(133)[a]	44.7(208)
1967		
1968	30.5	36.0
1969	13.1	14.2
Total	43.6(413)	50.2(444)
Hell Creek plant 1967 (standard-size fish)		
Within 71 days	35.2	42.0
In 72–302 days	23.9[b]	34.2[b]
In 303–362 days	19.8[b](91)	24.5[b](119)
1967 (large-size fish)		
Within 71 days	36.1	45.0
In 72–302 days	20.9[b,c]	33.7[b c]
In 303–362 days	10.6[b](119)	15.3[b](209)
1968		
Within 14 days	82.9	81.0
In 15–71 days	76.6	70.1
In 72–291 days	23.8	18.3
In 292–353 days	19.3(269)	13.8(268)
1969		
Within 14 days	89.4	89.0
In 15–71 days	82.0(255)	82.4(255)
Walden Pond plant 1968		
Within 14 days	83.4[e]	89.4[e]
In 15–71 days	42.9[b]	42.9[b]
In 72–321 days	18.8[b](265)	22.0[b](265)
1969		
Within 14 days	83.4	81.9
In 15–71 days[d]	19.2(265)	19.2(265)
Michigan River plant 1969		
Within 28 days	4.0	4.4
In 29–38 days	7.4	7.4
In 39–72 days	22.8	26.8
Total	34.2(272)	38.6(272)

[a] Number of fish stocked.
[b] Adjusted for known handling mortalities.
[c] Significantly different, P = .02.
[d] Total fish not recovered by draining.
[e] Significantly different, P = .04.

Reproducibility of Stamina Indices

Most high-stamina rainbow trout (90%) that were tested a second time during 1967–69 were again rated high (Table 3). The 95% confidence interval was 87–92%. Though 10% showed reduced stamina, only

TABLE 3. Performances of low- and high-stamina hatchery rainbow trout in a second test in the stamina tunnel during various years. During the first test, the performance index was 6 for all low-stamina groups, and 80 for all high-stamina groups.

	Low-stamina group				High-stamina group			
Sampling period	No. fish	Performance index[a]	% again rated low	% rated high[b]	No. fish	Performance index[a]	% again rated high	% rated low[b]
Avg 1967–69	291	35	27	28	631	76	90	1
Hell Creek 1970	487	44	23	35	482	75	88	<1
Walden Pond 1970	500	35	26	28	483	69	72	4
Avg 1970	987	39	25	31	965	72	80	2

[a] Average minutes the group swam in the stamina tunnel.

[b] The remaining percent of the fish were between the low- and high-stamina groups.

1% were rated low. The remaining 9% swam between 79 and 11 min. The small change in stamina was also reflected by the average group performance index, which decreased only slightly from 80 to 76 min.

Only 27% (95% C.I. = 22–33%) of the low-stamina fish were again rated low. Slightly more, 28% (95% C.I. = 22–34%), swam 80 min and were rated as high in stamina. The remaining 45% swam between 11 and 79 min. This marked increase in stamina rating was also reflected by the group performance index, which rose from 6 to 35 min. By the testing precedures used, only about one-fourth of the low-stamina fish could actually be considered as low in stamina following a second testing. The other 75%, although appearing to be low in stamina in the first test, apparently had the physical ability to swim better, as demonstrated in the second test.

Recaptures of Fish Rated Twice

Totals of 270 high-high-stamina, 110 low-low-stamina, and 150 low-stamina fish that improved stamina (11–40 min) on the basis of retesting were stocked in Hell Creek in 1970. These fish changed stamina groups much as did those tested in 1967–69 (Table 3). Recovery was high and the low-low-stamina group appeared to have the highest return, but the difference in recoveries was significant ($P = 0.04$) only between these and the group with improved stamina (Table 4). When the data for the low-low- and changed low-stamina groups were combined, to be comparable to those for low-stamina fish in the previous tests, survival was not significantly different between high- and low-stamina groups.

Also in 1970, totals of 129 low-low-stamina, 343 high-high-stamina, and 178 changed low-stamina (11–40 min) were stocked into the Walden Pond. These fish changed stamina groups upon retesting much as did the Hell Creek fish and those in 1967–69 (Table 3). Returns (Table 4) were about the same as for most recoveries within 71 days of fish rated once. No significant difference was found between stamina groups, but the same trend as at Hell Creek was observed. When data for the low-low- and changed low-stamina groups were combined, to be comparable to those for low-stamina groups on the basis of one rating, survival was nearly identical to that of high-stamina fish.

TABLE 4. Percentage recoveries of trout rated twice for stamina from two study areas within 71 days of stocking, 1970.

	Stamina group		
Area stocked	Low-low	Low changed to 11–40 min	High-high
Hell Creek	64.5(110)[a]	50.0(150)[b]	60.7(270)
	56.2		60.7
Walden Pond	49.6(129)	39.3(178)	42.8(343)
	43.6		42.8

[a] Number of fish stocked.

[b] Significantly different ($P = 0.04$).

Discussion

Throughout this study, no conclusive difference in survival due to stamina was demonstrated in the lentic environments. It is easy to rationalize that physical stamina would not be nearly as important in a lake as in a stream habitat. A stamina advantage, then, should at least result in better survival in a stream.

But of the 15 periods for stream recoveries of fish rated once, only one showed a significant difference between stamina groups. This was at Hell Creek in 1967 between the 71-day overwinter recoveries of large fish. At later and earlier recoveries, the same fish had no difference in survival. This one instance can hardly be interpreted as substantiating the hypothesis.

Nor, in the limited tests of fish rated twice, was a difference in survival found between the two groups. It is noteworthy that the low-stamina fish that improved swimming ability during the second "test" in the tunnel tended to be lowest in survival.

Whether survival of hatchery-reared rainbow trout can be predicted remains unknown. Vincent (1960) pointed out that stamina is certainly not the only factor that may aid in survival. Stamina may not be a limiting factor for survival, but it should at least produce a measurable effect to be a useful evaluation device.

In the present study, survival was not likely to be biased by differences in condition factor. Condition factor for all fish were well above 0.60–0.70, which was considered by Reimers (1963) to be marginal for vitality since individuals below this quickly tired from swimming.

Personnel of the Salmon-Cultural Laboratory have reported a significantly greater survival of high-stamina fall chinook salmon returning from the ocean (presented in part by Burrows 1966, 1969). However, the experimental designs differed considerably from those of the present study.

Results of the present study raise serious questions about the value of using present techniques of stamina tunnel evaluation in attempting to predict survival potential of domestic rainbow trout. Similar questions may also apply to other fish species, especially salmonids that have been reared under hatchery conditions. Increasing popularity of stamina tunnels and the assumption by investigators to intuitively associate a high-stamina rating with high-survival potential indicates that more studies are urgently needed.

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Burrows, R. E. 1966. Fingerling characteristics and adult survival. Progress in sport fishery research, 1965. U.S. Fish Wildl. Serv. Resour. Publ. 17: 38.

1969. The influence of fingerling quality on adult salmon survival. Trans. Amer. Fish. Soc. 98: 777–784.

Buscemi, P. A. 1961. Ecology of the bottom fauna of Parvin Lake, Colorado. Trans. Amer. Microsc. Soc. 80: 266–307.

Horak, D. L. 1969. The effect of fin removal on stamina of hatchery-reared rainbow trout. Progr. Fish-Cult. 31: 217–220.

Klein, W. D. MS 1967. *D. farionis* in rainbow trout. M.Sc. Thesis. Colorado State University, Fort Collins, Colo. 94 p.

Reimers, N. 1963. Body condition, water temperature, and over-winter survival of hatchery-reared trout in Convict Creek, California. Trans. Amer. Fish. Soc. 92: 39–46.

1966. A low-maintenance fish barrier with free-flow characteristics. Progr. Fish-Cult. 28: 103–107.

Thomas, A. E., R. E. Burrows, and H. H. Chenoweth. 1964. A device for stamina measurement of fingerling salmonids. U.S. Fish Wildl. Serv. Res. Rep. 67: 1–15.

Vincent, R. E. 1960. Some influences of domestication upon three stocks of brook trout (*Salvelinus fontinalis* Mitchell). Trans. Amer. Fish. Soc. 89: 35–52.

Evidence for a Home Site and Homing of Adult Yellowtail Rockfish, *Sebastes flavidus*

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CARLSON, H. R., AND R. E. HAIGHT. 1972. Evidence for a home site and homing of adult yellowtail rockfish, *Sebastes flavidus*. J. Fish. Res. Bd. Canada 29: 1011–1014.

Existence of a home site and homing ability was established for adult yellowtail rockfish, *Sebastes flavidus* (Ayres). Fish returned to the home site from as far as 22.5 km, some after displacement to other schools of the species and some after 3 months in captivity. Stretches of deep open water appeared to pose a hindrance to homing. Intensive fishing of a localized adult stock could cause a long-term decline in its abundance.

CARLSON, H. R., AND R. E. HAIGHT. 1972. Evidence for a home site and homing of adult yellowtail rockfish, *Sebastes flavidus*. J. Fish. Res. Bd. Canada 29: 1011–1014.

Nous démontrons chez la rascasse à queue jaune adulte, *Sebastes flavidus* (Ayres), l'existence d'un gîte et l'aptitude à y retourner. Les poissons retournent au gîte à partir de distances allant jusqu'à 22.5 km, quelques-uns après transfert à d'autres bancs, d'autres après 3 mois de captivité. Une étendue d'eau libre profonde semble être un obstacle au retour au gîte. La pêche intensive d'un stock adulte localisé pourrait, à long terme, occasionner un déclin d'abondance.

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THE yellowtail rockfish, *Sebastes flavidus* (Ayres), is a common demersal species along the western coast of North America and is utilized in both sport and commercial fisheries. Observations by sport fishermen and scuba divers indicate a disjunct distribution of schools of adult yellowtail rockfish in southeastern Alaska. If these schools are discrete, as has been found in California for the blue rockfish, *S. mystinus* (Miller et al. 1967), such discreteness would be important in management of the fishery.

In this study, we consider the two closely related questions of a home site and homing for adult yellowtail rockfish. Home site is defined as the particular locality to which an animal displays attachment or association (termed "localization" by Scott 1958), and homing is the return of an animal to a place formerly occupied rather than to other equally probable places. We use homing and home site in the same sense as has Gerking (1959), but also agree with Green (1971) that homing implies some navigational ability.

Homing (in the sense we use it) has been demonstrated for only six species of demersal marine fishes. These were tidepool or reef fishes, however, and the distances they traveled were generally less than 100 m.

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To investigate the discreteness of adult schools of yellowtail rockfish, we tagged fish taken from (what we supposed to be) a discrete school inhabiting the wreckage of a large vessel at Lena Point in Favorite Channel, near Juneau, Alaska (Fig. 1). We displaced some of the fish to locations as far as 35 km away, released others at the wreck as controls, and then attempted to recover the tagged fish. We selected release sites that would enable us to compare the ability of fish to return from sites along the same coastline and sites across open water, and also to test the inclination of fish to return from two sites inhabited by other schools of adult *S. flavidus*.

Materials and Methods

The fish for tagging were captured by hook and line. They ranged from 280 to 411 mm in fork length (average 355 mm) and from 7 to 16 years of age (average 9 years). Analysis of scales from 283 specimens showed that the school comprised mainly fish from two year-classes (1960 and 1961) during the 2-year period of the study. A Floy FD-67 anchor tag of vinyl plastic "spaghetti" tubing 7.6 cm long was inserted into the dorsal musculature of each fish. The tags were serially numbered and were color coded so that divers could identify them.

Between August 1969 and September 1970, 337 fish were tagged and released (Table 1). Twenty-four were released at Lena Point, and 313 were displaced to 11

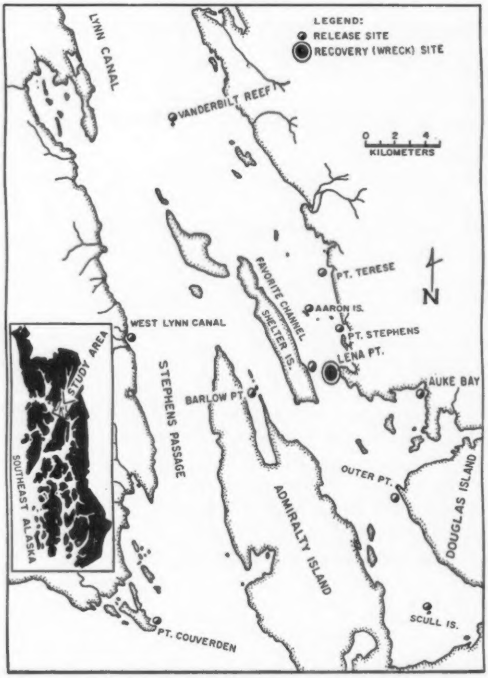

FIG. 1. Sites near Juneau, southeastern Alaska, where yellowtail rockfish were released and recaptured.

other sites. Three of the sites were along the mainland coast and eight were across open water (Fig. 1). The fish were transported to the release sites by skiff and were held en route in covered 114-liter plastic barrels filled with sea water. They were released over depths of 7 – 18 m (similar to the depths of capture). The distances between Lena Point and the other release sites ranged from 2.4 to 35.0 km.

About half of the fish were released on the day they were tagged, and the others were released later. The later releases included 127 fish that had to be held until the weather moderated enough for us to reach the most distant release sites in a small boat (3–13 days), 34 that were held at the Auke Bay Laboratory for 3 months to enable us to assess tag retention, and four that were held for 1 month so that we could evaluate a late-season release (November).

We did not attempt a random recovery effort of tagged fish throughout the general area because the schools of yellowtail rockfish were known to inhabit only certain sharply defined locations. Our main tag recovery efforts were at the wreck site, using hook and line. We also fished with hook and line at Point Terese, Point Stephens, and Barlow Cove and fished with trammel nets at Aaron Island. Auke Bay Laboratory scuba divers looked for tagged fish in the yellowtail rockfish schools that inhabited the release sites at Point Terese, Point Stephens, and Vanderbilt Reef. Many sport and commercial fishermen use the study area, and their fishing effort (although not measured) greatly exceeded ours in both time and distribution. A tag reward of two dollars was publicized in a local newspaper, on a radio program, and on posters at marinas in the area.

We made most of the tag recoveries, but some were made by sport and commercial fishermen. Although most of the recoveries were from hook and line fishing, laboratory divers captured some tagged fish with spears and made visual identification of others.

Results

Of the 337 tagged fish released over a 15-month period, 74 (22.0%) were recaptured at the wreck site at Lena Point (Table 1). Only two fish (0.6%) were recaptured away from Lena Point, one at Vanderbilt Reef and the other near Barlow Point. Half of the control fish released at the wreck site were recaptured there; individual fish were recaptured (and subsequently released) as many as five times over time spans of up to 9 months.

The highest percentages of tag returns were from fish released at the point of original capture (Lena Point) and at other sites on the mainland coast. Returns from sites across open water were much lower. Among the highest returns were those for fish displaced to locations inhabited by schools of yellowtail rockfish (Point Stephens and Point Terese) and fish held in captivity for 3 months before release.

The time interval between release and recapture of the first fish from each group ranged from 4 to 42 days. The longest time at liberty for any fish was 428 days, a fish released at Auke Bay in August 1969 and recaptured at Lena Point in October 1970.

Discussion

Clearly, the yellowtail rockfish we studied have a home site and homing ability. That the wreck at Lena Point is a home site is evidenced by recaptures of different fish from the same release over successive years and of the same fish several times (up to five times) at this location.

We believe that yellowtail rockfish demonstrated a marked homing ability. Nearly half (45.9%) of the fish displaced along the mainland coast were recaptured at the wreck site (including 12 by sport and commercial fishermen), and none were recaptured elsewhere. If the displaced fish had moved randomly, the sport and commercial fishery effort (which was more or less randomly distributed) should have produced recaptures from many locations other than the wreck (home) site. Thus, we feel that the fish directed their movement toward

TABLE 1. Release and recovery information for tagged yellowtail rockfish (*S. flavidus*) from the Point Lena wreck site which were displaced from or released at that site between August 1969 and September 1970.

Release site	Km from wreck site	Time of release	Fish released	Time until first fish recovered (days)	Fish recovered (%)	
					Wreck site	Other sites
Lena Point (wreck site)	–	October 1969, June 1970	24	11	50.0	0.0
On mainland coast						
Point Stephens	2.4	September 1970	12	10	50.0	0.0
Point Terese	8.0	November 1969, May 1970	39[a]	28	41.0	0.0
Auke Bay	8.0	August 1969	34[b]	19	47.0	0.0
Total	–	–	109	–	45.9	0.0
Across open water						
Shelter Island	2.4	May, June 1970	11	4	36.4	0.0
Aaron Island	4.8	May 1970	30	17	33.3	0.0
Barlow Point	8.0	June 1970	27	38	11.1	3.7
Outer Point	10.4	June 1970	33	41	9.1	0.0
Scull Island	19.3	August 1970	32[c]	42	3.1	0.0
Vanderbilt Reef	22.5	August 1970	33[c]	31	9.1	3.0
West Lynn Canal	22.5	August 1970	33[c]	–	0.0	0.0
Point Couverden	35.0	August 1970	29[c]	–	0.0	0.0
Total	–	–	228	–	10.5	0.9
Grand total	–	–	337	–	22.0	0.6

[a] Includes four fish held in captivity for 1 month before release.

[b] Fish held in captivity for 3 months before release.

[c] Fish held in captivity for 3–13 days before release because of poor weather.

the home site, i.e. they could navigate. Additionally, we have preliminary evidence (unpublished data) from electronic tracking experiments and scuba diver observations of displaced fish which indicates that their movement was directed (quite precisely in some instances) and was not random or haphazard.

The strength of association with a home site may be measured by the high returns from releases at the two sites known to be inhabited by other schools of yellowtail rockfish and by the memory shown by returning fish held in captivity before release. Returns from the Point Terese and Point Stephens release sites (where the presence of yellowtail rockfish demonstrates the suitability of the locations) suggest that association with a specific home site is not due merely to accessibility or suitability. The high returns of fish held captive for 3 months before release at Auke Bay indicate a lasting memory for the home site.

A partial barrier or hindrance to homing may exist in the form of open stretches of deep water. The percentage of recaptures of fish displaced to sites along the mainland coast was over four times that of fish displaced to sites across open water where depths were in excess of 100 m (45.9% vs. 10.5%). These sharply contrasting rates of recapture may be due to the hazards of traversing open water or to disorientation if visual contact with the substrate is lost. Quast (1968) discusses the dependence of certain California demersal fishes on visual contact with fixed objects in order to remain in a selected locale.

This study adds another group of fishes (the Scorpaenidae) to the few types of demersal fishes in which a home site and homing have been demonstrated. Homing in the sense we use the term was observed in displacement studies of the gill-finned goby, *Bathygobius soporator*, (Beebe 1931); the juvenile opaleye, *Girella nigricans*, and the wooly sculpin, *Clinocottus analis*, (Williams 1957); the tidepool sculpin, *Oligocottus maculosus*, (Green 1971); and the Nassau grouper, *Epinephelus striatus*, and the red hind, *E. guttatus*, (Bardach 1958). These studies involved homing only short distances (generally less than 100 m), in contrast to our study in which yellowtail rockfish returned to their home site from as far as 22.5 km.

In view of the yellowtail rockfish's association with a specific site and the slow growth and great longevity of the species (Phillips 1964), it is apparent that an intensive localized fishery on an adult stock could easily cause a long-term decline in its abundance.

Acknowledgments

The authors wish to thank the biologist scuba divers of the Auke Bay Fisheries Laboratory for their assistance, particularly L. M. Barr and R. J. Ellis.

Bardach, J. E. 1958. On the movements of Bermuda reef fishes. Ecology 39: 139–146.

Beebe, W. 1931. Notes on the gill-finned goby, *Bathygobius soporator* (Cuvier and Vallenciennes). Zoologica 12: 55–65.

Gerking, S. D. 1959. The restricted movement of fish populations. Biol. Rev. 34: 221–242.

Green, J. M. 1971. High tide movements and homing behaviour of the tidepool sculpin *Oligocottus maculosus*. J. Fish. Res. Bd. Canada 28: 383–389.

Miller, D. J., M. W. Odemar, and D. W. Gotshall. 1967. Life history and catch analysis of the blue rockfish (*Sebastes mystinus*) off central California, 1961–65. Calif. Dep. Fish Game MRO 67–14.

Phillips, J. B. 1964. Life history studies on ten species of rockfish (genus *Sebastodes*). Calif. Dep. Fish Game Fish Bull. 126: 70 p.

Quast, J. C. 1968. Fish fauna of the rocky inshore zone, p. 35–56. *In* W. J. North and C. L. Hubbs [ed.] Utilization of kelp-bed resources in southern California. Calif. Dep. Fish Game Fish Bull. 139: 264 p.

Scott, J. P. 1958. Animal behavior. University of Chicago Press, Chicago, Ill. 281 p.

Williams, G. C. 1957. Homing behavior of California rocky shore fishes. Univ. Calif. Publ. Zool. 59: 249–284.

The Structure of the Attachment Organ of Lernaeopodidae (Crustacea: Copepoda)

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KABATA, Z., AND B. COUSENS. 1972. The structure of the attachment organ of Lernaeopodidae (Crustacea: Copepoda). J. Fish. Res. Bd. Canada 29: 1015–1023.

The morphology and the anatomy of the bulla, a unique attachment organ of the parasitic copepods belonging to Lernaeopodidae (Caligoida) is described. By their anatomy the bullae can be divided into three types, associated with three groups of fishes: freshwater teleosts, marine teleosts, and elasmobranchs. The evolution of Lernaeopodidae is briefly outlined. The authors point out that the type of the bulla appears independent of the phylogenetic position of the parasite but is related only to the type of the host. It is concluded that the bulla is more than an attachment organ and that it enters into physiological association with the tissues of the fish.

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Nous décrivons la morphologie et l'anatomie de la bulle, organe de fixation unique chez les copépodes parasites de la famille des Lernaeopodidae (Caligoida). Selon son anatomie, la bulle se divise en trois types, associés à trois groupes de poissons: téléostéens d'eau douce, téléostéens marins et élasmobranches. Nous résumons brièvement l'évolution des Lernaeopodidae. Nous faisons remarquer que le type de bulle semble indépendant de la position phylogénétique du parasite, mais est plutôt lié au type d'hôte. Nous en concluons que la bulle est plus qu'un organe de fixation, et qu'elle forme une association physiologique avec les tissus de l'hôte.

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AMONG Copepoda parasitic on fishes, those belonging to the family Lernaeopodidae occupy a unique position with regard to their mode of attachment. The way in which the lernaeopodids maintain their contact with the host fish can be seen as a balanced compromise between the security of attachment and the ability, however limited, to alter position on the surface of the host. The attachment is effected by the bulla, an anchoring organ produced by the parasite and embedded in the tissues of the fish. One end of the bulla is permanently fused with the second maxillae, usually long, cylindrical, arm-like appendages of the parasite. It is due to the contractility of these appendages that the parasite is capable of shifting its position on the fish, within the radius determined by their length.

The harmful effects exerted by a lernaeopodid on its host fish can be resolved into two components; feeding activity of the parasite and its attachment. Neither of these components can be assessed with any accuracy at present. In the course of the work, reported on in this paper, the authors attempted to gain a closer understanding of the attachment organ itself, with the view to the subsequent extension of this knowledge to the effects produced by the presence of the attachment organ in the tissues of the fish.

Materials and Methods

Serial sections were prepared of the attachment organs of the following 24 species of Lernaeopodidae:

1. *Salmincola salmoneus* (Linnaeus)
2. *S. californiensis* (Dana 1852)
3. *S. extumescens* (Gadd 1901)
4. *S. thymalli* (Kessler 1868)
5. *Achtheres percarum* Nordmann 1832
6. *Coregonicola baicalensis* Koryakov 1951
7. *C. orientalis* Markevich and Bauer 1950
8. *Tracheliastes maculatus* Kollar 1835
9. *T. polycolpus* Nordmann 1832
10. *Nectobrachia indivisa* Fraser 1920
11. *Vanbenedenia chimaerae* (Heegaard 1962)
12. *Ommatokoita elongata* (Grant 1827)
13. *Lernaeopodina cluthae* (T. Scott 1901)
14. *Schistobrachia tertia* Kabata 1970

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15. *Dendrapta cameroni* (A. Heller 1949)
16. *Charopinus dubius* T. Scott 1901
17. *Pseudocharopinus dentatus* (Wilson 1912)
18. *Lernaeopoda bidiscalis* Kane 1892
19. *Brachiella robusta* (Wilson 1912)
20. *B. merluccii* Bassett-Smith 1896
21. *Clavella stellata* (Krøyer 1838)
22. *C. adunca* (Strøm 1762)
23. *Alella pagelli* (Krøyer 1863)
24. *Clavellodes rugosa* (Krøyer 1837)

Most specimens came from the collection of the senior author, gathered from many sources and not always fixed in the same manner. Usual fixation was in formalin solution (varying from 4 to 10%). The collection is stored in 70% ethanol to which a small amount (about 1 part in 10) of glycerine had been added. Specimens attached to host tissues containing bone or scales were decalcified in 5% trichloroacetic acid for 24 hr, prior to dehydrating and embedding in paraffin. Serial sections were cut in both transverse and sagittal planes, at either 6 or 8 μ in thickness. They were successively stained with celestine blue B, Harris' haematoxylin, and Mallory-Heidenhain one-step triple stain (Humasen 1967), with results satisfactory for the purpose. In addition, several series of *Salmincola californiensis* and *Pseudocharopinus dentatus* were stained with Harris' haematoxylin and eosin. Stained sections were mounted in Permount. It was found that the stain reaction of the bulla to Mallory-Heidenhain could be correlated with its hardness. Soft bullae stained a uniform blue. With increasing hardness they stained purple, red, yellow, and brown.

When possible, at least two specimens of each species were sectioned and examined. Five or six specimens were sectioned of those species that occur in British Columbia and are fairly abundant.

Description of Attachment Organs

It is only very imperfectly known how the attachment organ, or bulla, is produced by copepods belonging to the Lernaeopodidae. This family contains about 250 species, but the development of the bulla has been studied in only two species of the genus *Salmincola* (*S. salmoneus* and *S. edwardsii*). As far as one can infer from the progress of development of the bulla in these two species, the formation of this organ takes place in the frontal region of the cephalothorax. The bulla, folded upon itself and crumpled, is then extruded and implanted in the tissues of the host, in a cavity excavated by the parasite's appendages. Implantation completed, the parasite places its second maxillae in contact with the proximal end of the bulla. There follows a permanent fusion of the appendages with the bulla, the second maxillae insinuating their sharp processes, the maxillary plugs (Fig. 16e) into the ducts of the bulla. An important part in the process of fusion is played by the adhesion of the cuticle of the second maxillae to the surface of the bulla, promoted by a cement substance (Fig. 16d). Neither the origin of the substance nor the mechanism of the process have been determined.

As will become evident, fairly extensive differences exist in the structure of the bulla of different lernaeopodids. Most of the component parts occurring in this organ are shown in the diagram of the bulla of *Pseudocharopinus dentatus* (Fig. 16). Since no earlier work exists on this topic, it is necessary to accept some new terms in designating these parts. The bulla can be divided into two main parts, the handle or manubrium (c) and the anchor. The latter cannot be clearly delimited from the former. In essence, it is the expansion of the manubrium, which provides the surface intimately associated with the tissues of the host. For the sake of convenience, the surface of the anchor nearer the parasite is referred to as the supra-anchoral surface and that nearer the host as subanchoral surface. In some bullae the matrix of the anchor is divided into two layers, the supra-anchoral layer (g) which is continuous with manubrium and the subanchoral layer (i), or the sole of the anchor. A fibrous or granular layer (h) divides these two, except along the margins of the anchor. The entire bulla is covered by a thin hyaline layer, the pellicle (f), sometimes ill-defined along the subanchoral surface. The manubrium is pierced longitudinally by two wide ducts (k), penetrated by the maxillary plugs (e) and either continuing into the anchor without much change in girth, or undergoing modifications, discussed later in this section.

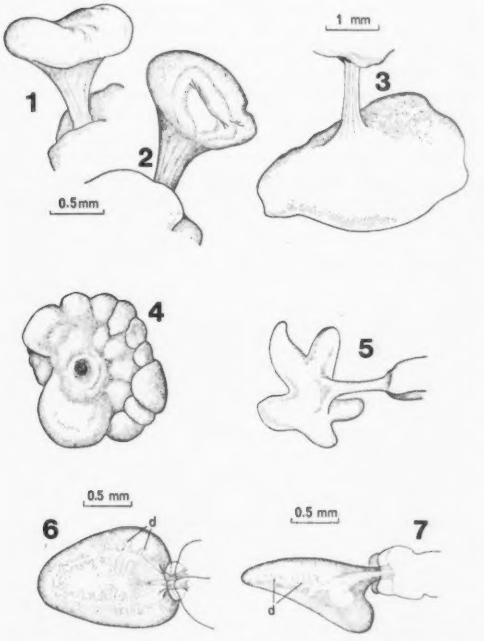
The attachment organ of *Salmincola californiensis* (Fig. 1 and 2) can serve as an example of a primitive type of bulla. The manubrium of this bulla flares out in a funnel-like manner and is about as long as the diameter of the anchor. The anchor is suborbicular (its definitive shape depends to some extent on the conditions prevailing at the site of attachment), plano-convex ideally, though its rim tends to curl towards the supra-anchoral surface (Plate I, 1). The plane of the long diameter of the disc is nearly perpendicular to the long axis of the manubrium.

Extensive modifications from the above type can occur by means of the following changes: (a) enlargement or reduction in size of the anchor; (b) change in shape of the anchor; (c) elongation, shortening or disappearance of the manubrium; and (d) alteration in the alignment of the anchor and the manubrium. Two or more of these changes can take place concurrently.

Changes can occur also in the internal structure of the bulla. According to the type of internal structure, the attachment organs of Lernaeopodidae can be divided into three groups (with few aberrant species, discussed later). Each group is associated with a different type of host fishes, namely freshwater teleosts, marine teleosts, and elasmobranchs.

Type I: Bullae of Lernaeopodidae Parasitic on Freshwater Teleosts

As mentioned above, the basic type of the bulla is represented by that of *Salmincola californiensis* (Fig. 1, 2; Plate I, 1). The range of modification of bullae of type I is quite broad. Modification due to enlargement of the anchor is shown by *Salmincola extumescens* (Fig. 3; plate I, 3). The diameter of the anchor of this species often exceeds the width of the parasite's trunk. Both enlargement and the change of shape of the anchor occur in the genus *Coregonicola*. The anchor of *Coregonicola baicalensis* (Fig. 4) is always larger than the cephalo-



FIGURES 1–7. Attachment organs of various Lernaeopodidae.
FIG. 1 and 2. Bulla of *Salmincola californiensis*; FIG. 3. Bulla of *S. extumescens*; FIG. 4. Bulla of *Coregonicola baicalensis*, with manubrium severed (redrawn from Koryakov 1951); FIG. 5. Bulla of *Salmincola stellata* (redrawn from Markevich 1956); FIG. 6 and 7. Bulla of *Salmincola salmoneus* (redrawn from Kabata 1969) (d = duct).

thorax of the parasite, has roughly a circular outline, and carries many ill-defined lobes, varying in number, shape, and position. The shape of the anchor is also modified in several species with stellate bullae. *Salmincola stellata* (Fig. 5), *Pseudotracheliastes stellatus* and *P. stellifer* have anchors in the shape of five- or six-pointed stars, their points often somewhat irregular and of uneven lengths. Another type of asymmetry is demonstrated by the so-called "hoof-shaped" bulla of *Salmincola salmoneus* (Fig. 6 and 7). The anchor of a hoof-shaped bulla is either orbicular or oval but has a more or less distinct indentation at one point, usually in the margin facing the posterior end of the parasite. It is near this indentation that the manubrium arises from the supra-anchoral surface, obliquely inclined to the plane of the long diameter of the anchor (Fig. 7). Similar, but more orbicular, is the anchor of *Salmincola edwardsii* (Olsson 1869). Reduction in size of the anchor is characteristic of the genus *Tracheliastes*, the anchor being represented by an inverted cone flaring out from the distal end of a short manubrium (Plate I, 4). At its subanchoral surface, the diameter of the anchor is barely more than three times that of the manubrium. The change in the alignment of the manubrium and the anchor is demonstrated by the bulla of *Salmincola thymalli* (Plate I, 2). In this clavate shape, the long diameter of the anchor and the long axis of the manubrium are parallel to each other and the division of the anchor into subanchoral and supra-anchoral surfaces disappears. Similar bullae occur also in species of the genus *Basanistes*, parasitic on freshwater fishes of the Palearctic. A variety of this shape is shown by *Basanistes briani* Markevich 1936, a parasite with the distal end of its cylindrical anchor expanded and asymmetrical. Another variation on the same theme occurs in the bulla of *Salmincola coregonorum* (Kessler 1868).

The variety of the external appearance is not reflected in the variety of the internal structure. The bulla of *Salmincola californiensis* can be used as an example of this structure (Plate I, 1). The section through the bulla shows that the manubrium accommodates two wide ducts (one of them is not shown in full in the section). The ducts leave the manubrium, entering the anchor and expanding in diameter. Running more or less in parallel with the margins of the anchor towards its anterior end, they ascribe an irregular semicircle and eventually meet and merge with each other. The matrix of the anchor is not divided into two layers. It is a reticulum of spongy substance, more or less fibrous in appearance. When recognizable, the fibers tend to run radially outwards from the centre of the anchor. Here and there a lacuna can be seen in the matrix. The matrix is slightly compressed and darker around the walls of the ducts and in the manubrium, both these areas tending to stain more darkly. The pellicle is thin and not everywhere easily delimited from the underlying matrix. Over the manubrium and, in some specimens, also over the adjacent part of the supra-anchoral surface, the pellicle stains red with Mallory-Heidenhain, indicating a greater degree of hardening. The red color, however, rapidly passes through shades of purple into dark blue. The entire bulla stains blue with triple stain, with the exception of the proximal, hard end of the manubrium which stains red.

The texture of the matrix varies from one species to another, though the type of matrix described above appears to be common. In *Salmincola thymalli* (Plate I, 2) the matrix of the clavate bulla is dense and homogeneous, staining purple and pierced by the very ample ducts running its entire length and joining at the distal end. In *Salmincola extumescens* (Plate I, 3) the central part of the anchor is filled with matrix clearly delimited from that of the peripheral part. The two parts are of similar texture, resembling that of *S. californiensis*, but differ in staining reaction. The central core stains a darker blue, indicating greater solidity and probably greater degree of hardness. The two ducts skirt the central core in their course through the anchor, providing at least in part the border line between the two portions of matrix. Species of the genus *Tracheliastes* (Plate I, 4) and *Achtheres percarum* have bullae with a completely different type of matrix. The anchor appears filled with thick strands, running perpendicularly to the long diameter of the anchor, from the level which can be roughly defined as the distal limit of the manubrium to the subanchoral surface.

Substantial empty spaces intervene between the fibers but the manubrium is solid and homogeneous.

In general, the features common to the bullae of type I are: (a) presence of two ducts continuing their courses through the anchor and uniting at the anterior margin (except for *Salmincola salmoneus*, Fig. 6 and 7, these ducts are simple tubular cavities); (b) blue color (or seldom purplish), when stained with the triple stain; (c) with few exceptions, large size of the anchor.

TYPE II: BULLAE OF LERNAEOPODIDAE PARASITIC ON MARINE TELEOSTS

The majority of species belonging to this group have bullae with short manubria and anchors with short diameters (usually not more than three or four times longer than those of manubria). The anchors are subspherical, lenticular, plano-convex, clavate, or cup-shaped. The aberrant *Nectobrachia indivisa* (Plate II, 3) has its cup-shaped anchor cut into an eight-pointed calyx, the points being divided into two groups of four (Fig. 8 and 9). The cup-shaped bulla is quite common, the shape being clearly derived from the lenticular or plano-convex anchor by deflexion of the periphery. (The opposite deflection in species of the preceding group (Plate I, 1) produces a typical mushroom characteristic of the group). A subspherical or slightly clavate bulla occurs in *Clavella adunca* (Plate I, 6). By elongation, this shape produces a fully clavate bulla, superficially similar to that of *Salmincola thymalli* (Plate I, 2). This type of bulla occurs in *Alella pagelli* (Plate I, 5). The opposite development, resulting in the flattening of the anchor, is found in *Clavella stellata* (Fig. 10; Plate II, 1). *C. stellata* has an orbicular anchor, indented on the posterior margin (Fig. 10) and with several (7–10) lacunae arranged in a peripheral circle. The point of origin of the manubrium is displaced from the center towards the posterior margin and the manubrium is inclined at a slight angle to the long diameter of the anchor. The species of this group show definite tendency towards the reduction in the size of the anchor. At least two species (*Brachiella robusta*, Fig. 11; Plate II, 2 and *Nectobrachia indivisa*, Fig. 8 and Plate II, 3) have flanges of pellicle, running round the circumference of the manubrium and outer wall of the cup-shaped anchor (in Fig. 8 these have been added to the original illustration, to show their position in section, Plate II, 3).

In general, however, the range of modifications of the attachment organ of type II is much narrower than that found in type I, particularly when one takes into account the fact that this group comprises the large majority of Lernaeopodidae.

The internal structure of the bulla of type II is clearly distinct from that of the preceding group. The main distinguishing feature is provided by the manubrial ducts. In the proximal part of their course, within the manubrium, these ducts are quite similar to those found in the bullae of the freshwater Lernaeopodidae. The similarity ends, however, at the distal end of the manubrium. At that point both ducts break up into several smaller ducts, some of these ducts subdividing again once or several times along their courses. Some narrow ducts arising from the primary division are shown in Fig. 8–10 and Plate I, 5, 6; Plate II, 1. The ducts, emerging from the manubrium in a cluster, run to the opposite end of the anchor, or its margin, commonly arranged in a peripheral ring (in bullae with spherical anchors) or in an outwardly radiating pattern (in bullae with flat discs, Fig. 10). The configuration of the fine ducts in the bulla of *Clavella adunca* was described in some detail in an earlier paper (Kabata 1963), when it was found that considerable intraspecific variability exists in the number and position of the ducts.

The bullae of the lernaeopodids parasitic on marine teleosts are rather more variable in their internal structure than are those of the parasites of freshwater fishes. The same is true of their reaction to the triple stain. The pellicle is less definite in this group, being recognizable only on or near the manubrium. The matrix of the bulla tends to be much more solid and appears harder. It is almost homogeneous in *Clavella stellata* (Plate II, 1), *C. adunca* (Plate I, 6) and *Alella pagelli* (Plate I, 5). In *Brachiella robusta* (Plate II, 2) it is slightly fibrous. The anchor of *Brachiella merluccii* stains a plum-coloured purple, that of *Clavella stellata* (Plate II, 1) dark red, that of *Alella pagelli* (Plate I, 5) reddish-brown, indicating higher degrees of hardness. The anchor of *Clavellodes rugosa*, a parasite with an interesting bulla not studied by the authors in sufficient detail due to lack of material, stains a peculiar pale violet color. In *Brachiella robusta* (Plate II, 2) and *Nectobrachia indivisa* (Plate II, 3), the softer condition of a part of the bulla is suggested by their blue color. Characteristically, both these species have pellicle flanges on the outer walls of their anchors. Some hardening of the outer surface of the anchor in the former species is suggested by the presence of the purple–red layer, becoming gradually thinner towards the margins of the anchor and extending distally about as far as the position of the distal-most flange. A cone of similar color is also visible in the centre at the bottom of the cup. The opposite condition occurs in the latter species, in which the inner core of the bulla stains red and the outer layers remain softer and stain blue. In most other species the color of the manubrium is yellowish-brown, indicating considerable hardness. In *Clavella adunca* (Plate I, 6) this color extends deeply into the centre of the anchor. A well defined border delimits this hard matrix of the manubrium from the rather softer, deeply red staining matrix of the anchor. Only seldom does one find in the bullae of a species of this group a tendency to divide into two layers (e.g. in *Brachiella merluccii*).

TYPE III: BULLAE OF LERNAEOPODIDAE PARASITIC ON ELASMOBRANCHS AND HOLOCEPHALANS

The only Lernaeopodidae known to parasitize holocephalans are two species of the genus *Vanbenedenia*. In most essential features the bullae of these species are similar to those of the parasites of elasmobranchs and can be discussed together. The majority of the lernaeopodids parasitic on elasmobranchs have bullae with short manubria and small, mainly subspherical, lenticular, or plano-convex anchors. The modification due to the enlargement of the anchor is characteristic of the genus

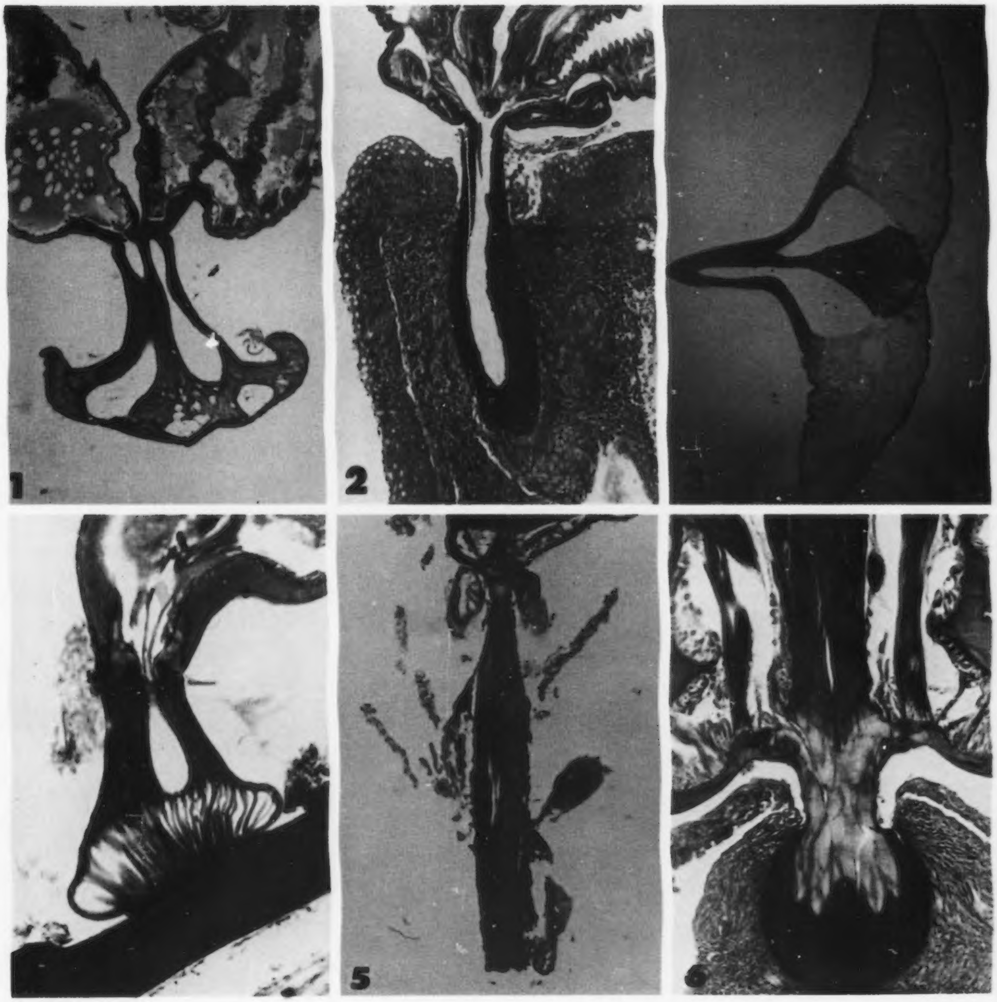


PLATE I. Sections through bullae of various Lernaeopodidae: 1, *Salmincola californiensis*; 2, *Salmincola thymalli*; 3, *Salmincola extumescens*; 4, *Tracheliastes polycolpus*; 5, *Alella pagelli*; 6, *Clavella adunca*.

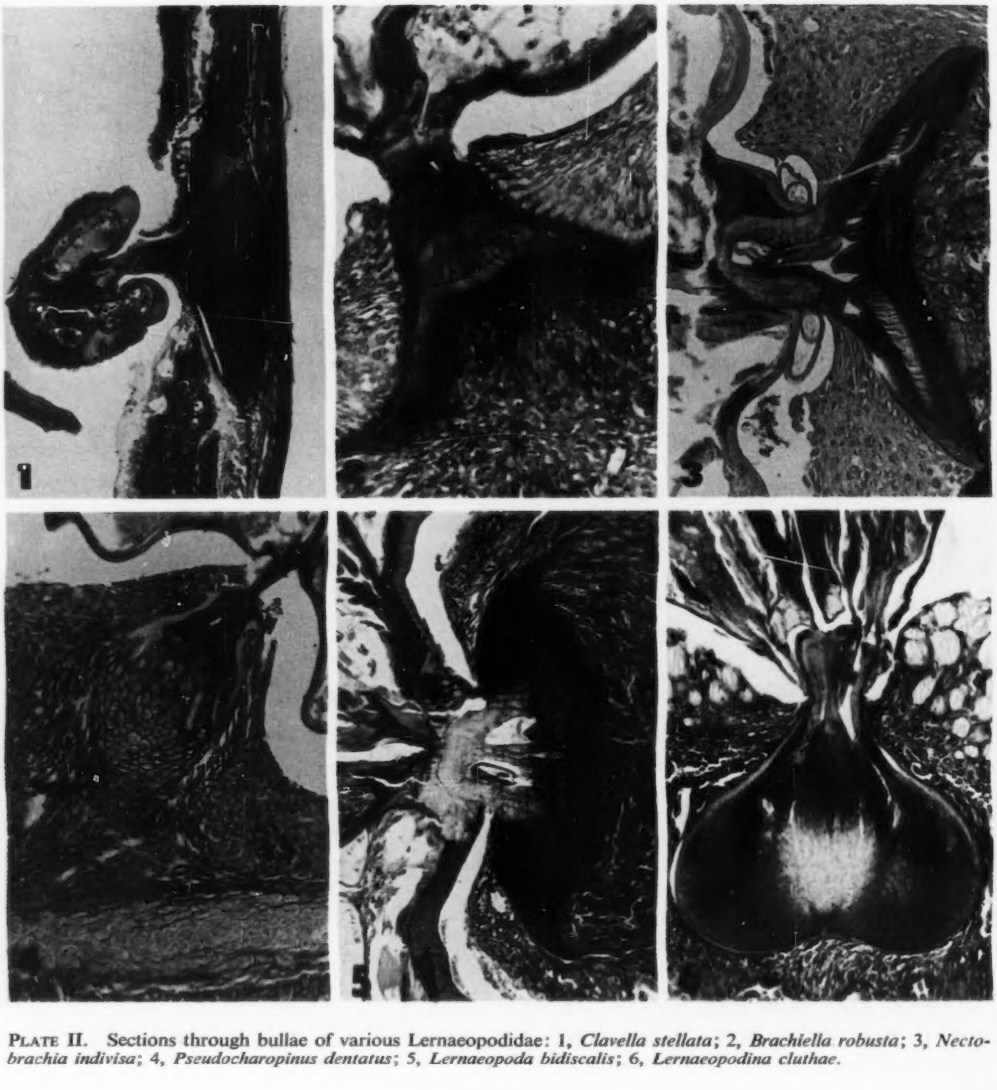
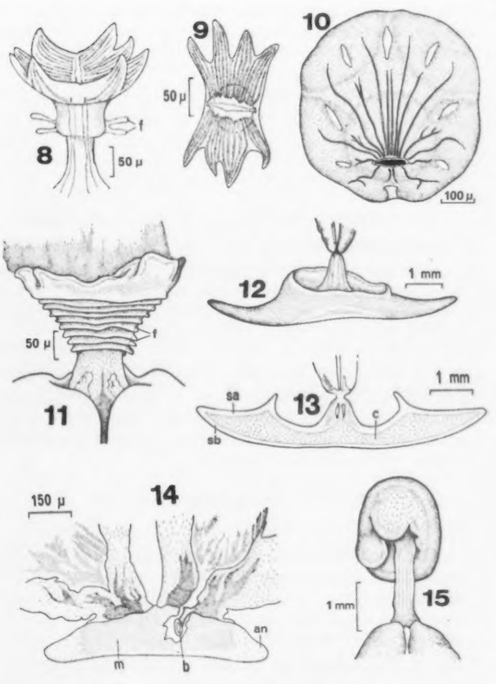


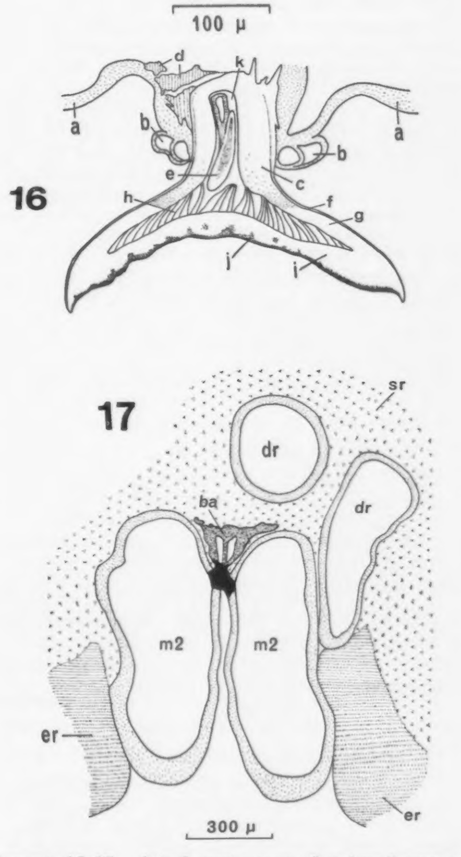
PLATE II. Sections through bullae of various Lernaeopodidae: 1, *Clavella stellata*; 2, *Brachiella robusta*; 3, *Nectobrachia indivisa*; 4, *Pseudocharopinus dentatus*; 5, *Lernaeopoda bidiscalis*; 6, *Lernaeopodina cluthae*.



FIGURES 8–15. Attachment organs of various Lernaeopodidae.
FIG. 8 and 9. Bulla of *Nectobrachia indivisa* (modified from Gusev 1951); FIG. 10. Bulla of *Clavella stellata*, with severed manubrium (redrawn from Kabata 1962); FIG. 11. Bulla of *Brachiella robusta* (redrawn from Kabata 1970a); FIG. 12 and 13. Bulla of *Charopinus dubius*, external appearance and diagram of section; FIG. 14. Bulla of *Ommatokoita elongata*, diagram of section; FIG. 15. Bulla of *Vanbenedenia chimaerae*. (an, anchor; b, maxillary plug; c, central layer; f, pellicle flange; m, manubrium; sa, supra-anchoral layer; sb, subanchoral layer).

Charopinus (Fig. 12 and 13). The members of this genus have anchors elongated in the plane perpendicular to the long axis of the manubrium and sometimes referred to as fusiform or boat-shaped. In some species the manubrium becomes very long (genus *Vanbenedenia*, Fig. 15), in others completely reduced (genus *Ommatokoita*, Fig. 14). In the latter case the maxillary plugs of the parasite are hooked directly into the anchor. (However, the differences in the reaction to stain suggest that the manubrium (Fig. 15m) is still present, though pushed into the anchor.) All members of the genera *Lernaeopoda*, *Lernaeopodina*, and *Pseudocharopinus* have bullae with short (sometimes barely discernible) manubria and small anchors, usually subspherical or plano-convex.

As in the two other types, the internal structure of the bulla of this group is characterized by the size and configuration of the manubrial ducts. The two large ducts extend only slightly beyond the distal end of the bulla and are only sufficiently long to accommodate the maxillary plugs (Fig. 16). In some instances they enlarge slightly at their distal ends. There appears to be no clearly defined connection between them and the subanchoral surface of the bulla, though the texture of the matrix is such as to suggest the existence of the connection via the capillary spaces between the components of the matrix.



FIGURES 16–17. Attachment organs of various Lernaeopodidae.
FIG. 16. Diagram of section through bulla of *Pseudocharopinus dentatus*; FIG. 17. Diagram of section through tips of second maxillae and vestigial bulla of *Dendrapta cameroni*. (a, cuticle of second maxilla; b, circumanubrial ring; ba, bulla; c, manubrium; d, cement substance; dr, section through dendrites; e, maxillary plug; er, skin; f, pellicle; g, supra-anchoral layer; h, central layer; i, subanchoral layer; j, accumulation of secretion; k, manubrial duct; m2, section through second maxilla).

The structure of the matrix varies within type III. The majority of species, represented by *Pseudocharopinus dentatus* (Plate II, 4) and *Lernaeopoda bidiscalis* (Plate II, 5), have bullae with distinctly fibrous anchors. The fibers radiate outwards from the bases of the manubrial ducts. It is difficult to see from the sections, whether each fiber runs the full distance between the duct and the pellicle of the subanchoral surface, or whether some of them branch. It would appear, however, that most of them are fairly long and no branching was found in sections. Some of them are arranged in bunches, arising from a small area at the base of the manubrial duct and separated from a similar area by a gap. The spaces between the fibers are not uniform throughout. In the space referred to as the central layer (Fig. 16h) they are much wider than in either supra-anchoral layer (Fig. 16g) or subanchoral layer (Fig. 16i). Though clearly defined, the borders between the central and the other two layers represent only the changes in the amount of space present between the fibers, not any change in the nature or continuity of the fibers themselves. In the subanchoral layer, next to the pellicle, the fibers are pushed apart by accumulation of hyaline, blue staining substance (Fig. 16j). The supra-anchoral, denser layer stains purple in *Pseudocharopinus dentatus* and yellow in *Lernaeopoda bidiscalis*, whereas the subanchoral layer is blue in the former and reddish-purple in the latter (except where filled with the blue hyaline substance). In other species (*Charopinus dubius*, Fig. 13) and *Lernaeopodina cluthae* (Plate II, 6) the matrix of the anchor is finely granular, either more or less uniform throughout (*L. cluthae*) or divided into the three layers, only the central violet layer being granular and the other two being almost homogeneous and red, with yellow pellicle (*C. dubius*).

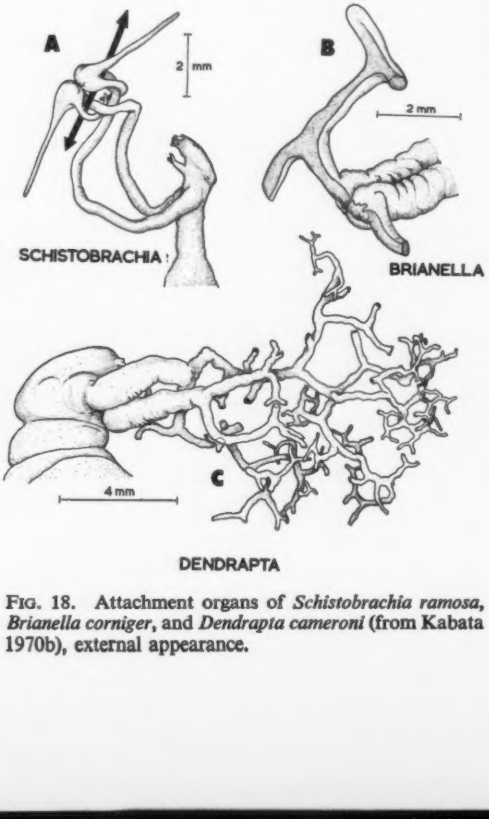

A
2 mm
B
2 mm
SCHISTOBRACHIA
BRIANELLA
C
4 mm
DENDRAPTA

FIG. 18. Attachment organs of *Schistobrachia ramosa*, *Brianella corniger*, and *Dendrapta cameroni* (from Kabata 1970b), external appearance.

The manubrium of type III bullae stains dark yellow, tinged in places with brown. The manubrium of the bulla of *Charopinus dubius*, exceptional in its nearly conical shape, stains yellow only in its central part, the outer layers assuming various shades of red to violet color.

The pellicle of type III bullae is not always distinct. In *Pseudocharopinus dentatus* (Plate II, 4) it can be seen as a thin yellow layer only near the manubrium on the central part of the supra-anchoral surface. In *Lernaeopodina cluthae* (Plate II, 6) and *Vanbenedenia* it shows as a fine blue layer around the anchor, whereas in *Charopinus dubius* it is yellow, but does not form a well delimited layer. In many species of this group (Plate II, 4) the subanchoral surface is ill-defined and appears to invade the host tissue, enclosing some host cells in vacuoles of hyaline secretion. The tissue of the host and the parasite become intimately intertwined.

Discussion

Lernaeopodidae are the only family of parasitic Copepoda with reasonably well known intrafamilial relationships. A family tree was worked out for them some time ago, though the work describing it was published in abstract only (Kabata 1966). It is pertinent to the discussion of the attachment organ of Lernaeopodidae that the reader be acquainted with their intrafamilial relationships. They are summarized in Fig. 19. The tree has been prepared on the basis of comparative morphology and currently

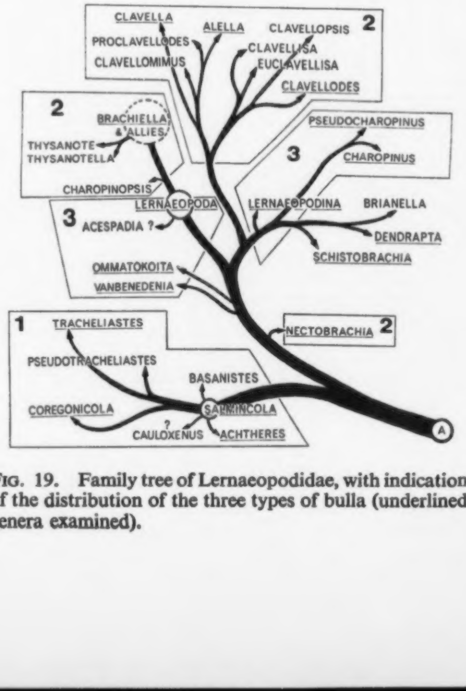

CLAVELLA
ALELLA
CLAVELLOPSIS
2
PROCLAVELLODES
CLAVELLISA
CLAVELLOMIMUS
EUCLAVELLISA
CLAVELLODES
2
BRACHIELLA & ALLIES
THYSANOTE
THYSANOTELLA
PSEUDOCHAROPINUS
3
CHAROPINUS
CHAROPINOPSIS
LERNAEOPODA
LERNAEOPODINA
BRIANELLA
3
ACESPADIA ?
DENDRAPTA
SCHISTOBRACHIA
OMMATOKOITA
VANBENEDENIA
1
TRACHELIASTES
NECTOBRACHIA
2
PSEUDOTRACHELIASTES
BASANISTES
COREGONICOLA
SALMINCOLA
?
CAULOXENUS
ACHTHERES
A

FIG. 19. Family tree of Lernaeopodidae, with indication of the distribution of the three types of bulla (underlined genera examined).

known details of the ontogenetic development. One of the important criteria used to assess a morphological feature as primitive or advanced is the extent to which this feature departed from the condition existing in the free-swimming copepodid of the species. Comparisons were also made between the appendages of Lernaeopodidae and corresponding appendages of species belonging to families recognized as less modified by the influence of parasitism (e.g. mandibles of various Lernaeopodidae were compared with the more primitive condition of the mandible among Caligidae). The detailed account of these relationships will be given elsewhere. For the purpose of this discussion it is sufficient to outline the authors' views on the evolution of Lernaeopodidae.

Beginning with a hypothetical ancestral form (marked A in Fig. 19), presumably parasitic on the elasmobranchs of its day, the family underwent its first major cleavage when some of its members became adapted to parasitization of salmonid migrants. With their newly acquired teleost hosts, these parasites invaded and radiated in freshwater habitats, spreading to fishes other than salmonids. This is indicated in Fig. 19 by the central position of the genus *Salmincola* in the freshwater branch of Lernaeopodidae. The genus *Achtheres* evolved in association with the percomorphfishes, while *Pseudotracheliastes* occurs in fishes of the ancient order Acipenseriformes.

The marine Lernaeopodidae continued their progress in association with the elasmobranchs, the main stem of development producing small offshoots, sometimes of a rather aberrant nature (e.g. genus *Nectobrachia*, exceptional in its parasitism on teleosts). The next major branching of the family tree separated species parasitic on sharks from those living on skates and rays. The parasites of sharks are grouped mainly in the genus *Lernaeopoda*, whereas those occurring on Hypotremata are members of the so-called "*Charopinus* group" (Kabata 1964). (There are some exceptions to this host association. For example, *Pseudocharopinus bicaudatus* (Krøyer 1837) is a member of the group living on Hypotremata but inhabits spiracles of dogfishes. On the other hand, *Schistobrachia chimaerae* (Yamaguti 1939) parasitizes a holocephalan. There are some records of occurrences of *Lernaeopoda* on the myliobatid rays. On the whole, however, the rule holds.)

The final development of Lernaeopodidae occurred with their acquisition of marine teleosts as hosts. This took place independently on two occasions. One group (*Brachiella* and relatives) developed from the parasites of sharks. The other, having split off at an early stage from the *Charopinus* group, produced a number of genera that might be referred to as the "*Clavella* group," from the name of its oldest established genus.

The branching of the family tree is not reflected in the structure of the bulla. The three types of bulla can only be related to the three categories of hosts. For the bulla of type I, occurring only in the parasites of freshwater fishes, an obvious coincidence exists between the type of host and the phylogenetic position of the parasite, since all freshwater lernaeopodids have bullae of type I and belong to the same phylogenetic branch. No such correlation, however, exists for the other two types of bullae. Type III occurs in two distinct groups of phylogenetically separate parasites. It is also found in the unrelated primitive genera *Vanbenedenia* and *Ommatokoita*. Type II also occurs in two independently evolved groups of parasites, as well as in an aberrant early offshoot, phylogenetically unconnected with either group.

It has been said previously that the three types of bulla differ from one another mainly in the dimensions and arrangement of their ducts. The functions of the ducts themselves, however, are less obvious. From the study of the development of *Salmincola californiensis* (cf. Kabata and Cousens unpublished data) we know that one of these functions is the inflation of the bulla within the cavity of implantation excavated in the host tissues. The inflation can only occur by influx of substances into the bulla, passed into it via the second maxillae by the parasite. Were the expansion of the bulla the only function served by the ducts within it, it would be hard to account for the differences in those ducts, correlated with the type of the host but independent of the phylogenetic position. It is quite possible that some substances produced by the parasite are transported to the bulla after its initial inflation. (Bullae of type II and III harden with age, possibly due to accumulation of such substances, or their residues within them.) Perhaps even excretion or secretion processes involve the bulla in depositing some of the parasite-made substances in the tissues of the host. Should this be the case, the three types of hosts would present different problems in these exchanges. Recent findings (Sundnes 1970) indicate that marine parasitic copepods are not necessarily isotonic with their hosts, as was previously suggested (Pannikar and Sproston 1941) but rather with their host's environment. Consequently, parasites of marine teleosts have to deal with hypotonic hosts, while those of elasmobranchs have to face the high urea content of their hosts' tissues, both factors of importance with respect to possible exchanges. Parasites of freshwater teleosts must encounter yet another entirely different set of problems. Though the osmotic relationships of freshwater Lernaeopodidae have yet to be investigated, it may be assumed that they are not isotonic with their environment, and might possibly approximate the osmolarity of their hosts. One might hazard a statement that the very fact of existence of types of bullae coincident with these three groups of hosts is suggestive of relationship between the host and the attachment organ more intimate than a simple mechanical implantation. The dynamic nature of the association can be suggested here as a mere speculation, but its possibility is so plausible that it is certainly worth a closer investigation.

Examining bullae sectioned in situ in their host tissues one is struck by the lack of vigour in the reaction of the host to the presence of the attachment organ, particularly evident in bullae of type I. In spite of a slight connective tissue reaction (Plate I, 2), the host tissue appears largely unaffected, except for the mechanical damage caused by the bulla. The type I bulla remains in a fairly soft (blue stain) condition throughout the parasite's life, suggesting that substances, if any, arriving in it or passing through it are different from those which cause hardening of the bullae of the other two types. The authors suggest that type I bulla is primitive as an attachment organ and functions as a grappling iron, maintaining its grip on the host tissue due to the large size and suitable shape of its anchor. The surface of the anchor is not intimately fused with the host tissue, so that type I bulla is easily dissected out. Incision of the overlying host tissue usually suffices to evulse the undamaged bulla, even when the latter is as large as that of *Salmincola extumescens* (Fig. 3). The exception to this condition is found in bullae attached, for example, to the scales of the fish and unable to expand under a suitably thick layer of tissue. Hence the bulla of *Tracheliastes* (Plate I, 4) has a small anchor, its subanchoral surface apparently possessing adhesive properties, suggested by differences in staining reactions of that area.

With very few exceptions, the opposite holds true for the bullae of types II and III. The usually small anchors of these bullae are often only superficially inserted into the host tissues. The tissue below the anchor, however, is clearly modified, as evident in the change of its stain reaction. Under most bullae of type II and III a plug of dark blue staining tissue is found (Plate II, 2, 4, 5, and 6) in which the components of the tissue are in evident disorder. The plug appears to consist of the connective tissue of the fish, permeated by some sort of adhesive substance produced by the parasite. As mentioned earlier, this hyaline and presumably adhesive substance is often seen in sections to contain inclusions of the host cells. With the lack of a clearly defined border of the subanchoral surface, these cells might be mistaken for the component elements of the bulla itself (Rigby and Tunnel 1971). The intimacy of association between the bulla and the host tissue is very well exemplified by *Nectobrachia indivisa* Plate II, 3). The octoradiate calyx of the bulla of this species contains between its "petals" a subspherical group of cartilage cells derived from the supporting rod of the gill filament. (What is the mechanism producing the close contact between the bulla and the rod, two structures fairly distant from each other, is unknown at this stage.) The hard ball of cartilage is very difficult to disengage from the bulla and has been mistaken on a previous occasion (Kabata 1970a) for a component part of that organ. In most instances it is very difficult to dissect out bullae of type II and III, even though they might not be surrounded by a plug of modified tissue (e.g. *Clavella adunca*, Plate I, 6). This difficulty suggests that the outer surface of the bulla, in contrast to those of type I, is adhesive. The exceptional bullae of type III that are not fused with the surrounding host tissue and are easily evulsed are unusually large and have a shape particularly suitable for anchoring (*Charopinus dubius*, Fig. 12).

A recent description of the structure of the bulla of *Pseudocharopinus dentatus* (cf. Rigby and Tunnel 1971) differs to some extent from the one given in this paper. In particular, the present authors were unable to find an epithelial cell layer on the subanchoral surface of the bulla. The fibers of the matrix are referred to by Rigby and Tunnel as "a thick connective tissue layer" and they do bear some resemblance to the connective tissue. The "capsular rods" are, of course, the maxillary plugs and do not constitute a part of the bulla.

This discussion would not be complete without taking note of three genera of Lernaeopodidae, hitherto believed to be either devoid of bulla (*Dendrapta*) or have it in vestigial condition (*Brianella*, *Schistobrachia*). The members of all these three genera (Fig. 18) are attached to their hosts by means of the tips of their second maxillae, modified into elaborate holdfast organs. Since the ontogeny of these parasites remains unknown, it was rather difficult to visualize the mode of the early attachment that had to follow the relinquishing of the frontal filament at the end of the chalimus stage. Sections through the base of the second maxillae of *Dendrapta cameroni* (Fig. 17) have shown, however, that the bulla, though reduced, is present, at least in the young adult female. It is now clear that the young *Dendrapta* produces the bulla and implants it in the usual manner. The implantation is followed by rapid development of the system of dendrites (Fig. 17 dr) from the tips of the second maxillae. These dendrites supersede the bulla as the attachment organ. The small bulla is reminiscent of type III in the presence of two blindly ending ducts. It has the shape of an inverted cone, flaring out from the base of the manubrium to the irregular subanchoral surface. Its soft condition is evident from its blue reaction to triple stain. With the expansion in the girth of the second maxillae and with repeated movements relative to each other (alternate contractions of the second maxillae are among the most common movements of Lernaeopodidae) it is probable that the bulla becomes eventually destroyed. The same perhaps is true of *Schistobrachia*. Although sections through the point of fusion of the second maxillae of *S. tertia* did not reveal the bulla, it was found that they remain linked by the remnants of a manubrium, with the proximal parts of manubrial ducts still recognizable and the maxillary plugs still inserted in the basal openings. The same can be presumed for *Brianella*. In the course of their development, then, the parasites belonging to these three genera change their attachment from the original grip by the second antennae of the copepodid to the frontal filament of chalimus, followed by a change to the bulla of the young adult, and its final replacement by the holdfast of the mature adult.

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HUMASEN, G. L. 1967. Animal tissue techniques. W. H. Freeman, San Francisco, Calif. 165 p.

KABATA, Z. 1963. *Clavella* (Copepoda) parasitic on British Gadidae: one species or several? Crustaceana 5: 64–74.

1964. Revision of the genus *Charopinus* Krøyer, 1863 (Copepoda: Lernaeopodidae). Vidensk. Medd. Naturhist Foren. Kjobenhavn 127: 85–112.

1966. Comments on the phylogeny and zoogeography of Lernaeopodidae (Crustacea: Copepoda). Proc. First Int. Congr. Parasitol. 2: 1082–1083.

1970a. Some Lernaeopodidae (Copepoda) from fishes of British Columbia. J. Fish. Res. Bd. Canada 27: 865–885.

1970b. Crustacea as enemies of fishes. *In* S. F. Snieszko and H. R. Axelrod [ed.] Diseases of fishes. Book I. T. F. H. Publications, Jersey City, N. J. 171 p.

PANNIKAR, N. K., AND N. G. SPROSTON. 1941. Osmotic relations of some metazoan parasites (*Lernaeocera*, *Bopyrus*). Parasitology 33: 214–223.

RIGBY, D. W., AND N. TUNNELL. 1971. Internal anatomy and histology of female *Pseudocharopinus dentatus* (Copepoda: Lernaeopodidae). Trans. Amer. Microsc. Soc. 90: 61–71.

SUNDNES, G. 1970. *Lernaeocera branchialis* (L.) on cod (*Gadus morhua* L.) in Norwegian waters. Inst. Mar. Res., Bergen. 48 p.

Migratory Movements of Adult Sockeye Salmon (*Oncorhynchus nerka*) in Coastal British Columbia as Revealed by Ultrasonic Tracking

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Individual courses, obtained by ultrasonic tracking nine sockeye in 1969 and nine in 1970, ranged up to 130.8 km (24.2 median) and 66.6 hr (9.6 median). Course directions were mainly to the north and west in 1969 and to the south and east in 1970. This difference may have arisen from differences in home river affiliation of the tracked sockeye. Swimming speeds showed a pronounced diel rhythm with higher values at 1400 hr and lower values at 0200 hr. The average speed of 53 cm/sec was consistent with rate of movement estimates obtained previously from tagging–recapture studies. A 13 cm/sec greater average speed in 1970 than in 1969 was observed, and possible reasons for the difference were discussed. Differences in speed within or beyond 2 km from land were not observed for either year. A diel rhythm in the magnitude of course change appeared, with a decrease in the frequency of large angular changes occurring in the afternoon. An orientation mechanism involving a daily reorientation process is hypothesized.

MADISON, D. M., R. M. HORRALL, A. B. STASKO, AND A. D. HASLER. 1972. Migratory movements of adult sockeye salmon (*Oncorhynchus nerka*) in coastal British Columbia as revealed by ultrasonic tracking. J. Fish. Res. Bd. Canada 29: 1025–1033.

Nous avons suivi à l'ultrason les déplacements individuels de neuf saumons sockeye en 1969 et de neuf autres en 1970 sur une distance allant jusqu'à 130.8 km (médiane 24.2) et pour une période maximale de 66.6 h (médiane 9.6). Les saumons se sont dirigés surtout vers le nord et l'ouest en 1969, et vers le sud et l'est en 1970. Cette différence est probablement due au fait que les saumons traqués appartiennent à différentes rivières d'origine. La vitesse de la nage accuse un rythme nycthéméral prononcé, avec maximum à 1400 h et minimum à 0200 h. La vitesse moyenne de 53 cm/sec est en accord avec les estimés obtenus antérieurement à la suite de marquages et de recaptures. Nous avons remarqué qu'en 1970 la vitesse moyenne a été de 13 cm/sec plus grande qu'en 1969. Nous examinons les raisons possibles de cette différence. Nous n'avons décelé aucune différence de vitesse à l'intérieur ou à l'extérieur de la limite de 2 km de la côte au cours de l'une ou l'autre de ces années. Nous avons observé un rythme nycthéméral de l'amplitude des changements de direction, les changements à grand angle devenant moins fréquents l'après-midi. Nous émettons l'hypothèse d'un mécanisme d'orientation impliquant un processus journalier de réorientation.

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THE breeding migration of sockeye salmon, *Oncorhynchus nerka*, as well as that of other salmon, is one of the most dramatic and yet little understood examples of migratory movement among animals. Since early in the 20th century, sockeye have been on the decline because of early mismanagement and overexploitation (Foerster 1968). According to Foerster, a knowledge of the movements and destination of sockeye caught along the coastal islands and river estuaries is important in determining the contribution of each river system to the total fishery, and subsequently, in modifying the commercial fishing patterns in such a way as to achieve a more controlled salmon harvest from the various coastal river systems. A more detailed record of the movement patterns is also prerequisite to understanding the orientation mechanisms that guide these fish.

The existing information on the coastal migratory movements of salmon has come from large-scale tagging and recapture studies such as reported by Williamson (1927, 1929), Rich and Morton (1929), Rich and Suomela (1927), and Aro and McDonald

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(MS 1968). Although some general estimates of travel time and directional tendency were obtained, little was learned about the specific migratory movements along the coast.

The method capable of giving the required details on movements of individual fish involves the use of miniature, fish-borne, ultrasonic transmitters (see reviews of Johnson 1971; Stasko 1971). Except for our studies (Hasler et al. 1970; Madison and Hasler 1971) and those of J. Johnson and I.Todd and J. Buxton (personal communications), little effort has been made at using ultrasonic transmitters to track salmon in coastal waters.

Our objectives were to investigate in detail the migratory movements of adult sockeye salmon approaching the coastal waters of British Columbia near the Nass and Skeena estuaries, and to evaluate the types of orientation mechanisms that could be used by the sockeye during this period. This paper evaluates the ultrasonic tracking procedure, provides a record of the courses taken by individual fish, and analyzes the course records for diel variations in swimming speed and straightness. A second paper will deal with environmental factors and hypotheses concerning orientation mechanisms.

Methods

HANDLING OF SALMON

Adult sockeye salmon were dipnetted from the closed purse seines of commercial fishing vessels north of Dundas Island off the British Columbia coast, just 10 km south of Alaskan waters. From one to three sockeye were brought onto the tracking vessel and put into a transport tank (1 × 0.7 × 0.7 m) that was supplied with running sea water. The salmon were then either taken to a submerged holding cage (2 × 2 × 1.3 m) in a nearby inlet or released at the capture site. Subsequent salmon for study were obtained either from the holding cage or from the purse seine of another commercial vessel.

For tagging and transmitter insertion, the salmon were mildly anesthetized with 45–90 ppm solution of 2-phenoxyethanol and sea water at an average temperature of 11 C (see Sehdev et al. 1963). Sex was not determined, but total length was measured. Scale samples were taken, and age-class was assessed (Clutter and Whitesel 1956). Transmitters were inserted down the esophagus of the salmon (11 in 1969, 10 in 1970). Care was taken not to rupture the delicate stomach linings or to cause gas expulsion from the air bladder. An alligator identification clip, modified from McCleave et al. (1967), was attached to the posterior margin of the dorsal fin of each salmon in 1969. These tagged salmon included 10 fish without transmitters. Both kinds of releases were performed in 1969 in hopes that recaptured sockeye would give us some idea of transmitter effects on movement. Only one recapture was made in 1969. Because of the inadequate recovery and our desire to minimize possible irritation effects, no clips were used in 1970.

After transmitter insertion, the anesthetic was flushed from the transport tank and the fish were allowed to recover for at least 15 min before release. Releases were made at the capture location, except those for sockeye 2, 4, and 5 in 1969. These were released from 3–8 km ENE of the capture point. The time between capture and release varied from 0.5 (immediate release) to 155.4 hr (released after 6 days in holding cage).

Adverse effects resulting from external tagging and handling operations mentioned by Verhoeven and Davidoff (1962) were considered to be minimal because of the individualized attention given to each salmon. Purse seine fish were not used that were thought to have had contact with jellyfish, or possessed scars or net abrasions. Only sockeye actively swimming in the closed seine were selected. Effects due to the internal transmitter are unknown for salmon. One obvious consideration would be the hydrostatic adjustment required by the addition of a negatively buoyant transmitter. Gallepp (MS 1970) has shown that bluegills (*Lepomis macrochirus*) under laboratory conditions require at least 3 hr to adjust hydrostatically to the simulated weight of a transmitter. During our ultrasonic tracking studies of 189 salmon of four species since 1967, the transmitter has not noticeably impeded sustained movement or successful return to home river systems. We have noticed a tendency for fish recently given a transmitter to delay leaving the release area for usually 30–60 min, but this delay may not be due to transmitter effects.

ULTRASONIC TRACKING EQUIPMENT

Two makes of 70 kHz ultrasonic transmitters were used: a Hydro-Space Systems Corp. unit in 1969 and a Smith-Root Electronics transmitter (SR69B) in 1970. Pulse rates varied from 60 to 180 per min to facilitate identification of the released fish. The Hydro-Space units were slightly larger and weighed more (38 vs. 20 g in air) than the Smith-Root transmitters, but had a shorter battery life (4 vs. 10 days). The effective signal range was 1.1 km for the Smith-Root unit and 1.4 km for the Hydro-Space unit.

An HRO-500 Receiver with LF-10 Converter (National) was the principal receiving unit. The HRO-500 was connected to a directional hydrophone that had a peak resonance frequency of 70 kHz and a sensitivity at this frequency of about -80 dB re 1 volt/μbar. The hydrophone, which was constructed in our laboratory, had approximately an 18 degree acceptance beam and was directed in a horizontal plane. It was mounted 1 m below the hull of the tracking vessel at the end of a 3.5-m iron pipe. Rotation was controlled manually. The tracking vessel was the M. V. *Noctiluca*, a 10 × 2.8 m single engine diesel craft capable of about 10 knots. An assist craft, a 3.7 m long inflatable rubber boat, was used mainly to help with water current measurements during tracking.

TRACKING PROCEDURES

After release of the salmon, positions were recorded once every 15–45 min. To obtain these readings, the intensity and directionality of the transmitter signal was used to maneuver the tracking vessel within about 50 m of the fish. Then, the tracking vessel's position, which was assumed to closely approximate the fish's position, was determined with a sextant (U.S. Navy Mark II) or, when visibility was reduced, with radar (Decca 101). When positions were not being determined, the tracking vessel was usually kept at least 200 m from the salmon to minimize the possibility of disturbance.

Current direction and speed were measured several times daily when visibility permitted by means of current drogues set at 3, 10, and 30 m.

DATA ANALYSIS

The plotted course for each salmon consisted of a series of points connected by lines, either straight or curved, that were thought to best represent the approximate course between the successive positions. Only those courses having at least three position points (nine tracks each year) were analyzed.

Two measures were used for detailed analyses of movements: swimming speed and angular change. To obtain this information, each course was given points at ½-hr intervals. The swimming speed for the interval was calculated using the distance moved along the estimated course. To obtain angular change (net course change), the points were connected by straight lines to form a new, though similar, course representation. Angular change was determined for each interval by measuring the change in direction in degrees between the straight line constructed for a given interval and the line for the interval immediately following. The resulting angles varied up to 180° right or left.

The direction of movement and the ½-hr estimates of swimming speed and angular change for each fish result from movement of both the fish and the water mass. To obtain true values, corrections would have to be made for water currents. These adjustments could not be made because current measurements were too infrequent. However, since current speeds averaged only about half the observed swimming speeds, the estimated courses were assumed to approximate the salmon's true orientation. Current speeds recorded in this study throughout the tracking area averaged 28.6 cm/sec with 74% (59 of 77) being 30 cm/sec or less.

Data from the sockeye of a given year were grouped for analysis according to time of day. For example, from all the 30 min speed estimates from the sockeye tracked in 1969, those estimates for the same ½ hr were averaged to give the mean speed for the interval. If a salmon was tracked for over 24 hr, the data for the same time interval from the different days were considered to be independent of each other and were included together in the calculation of the mean.

For the angular change analysis, angular means (Batschelet 1965), and not arithmetic means, were calculated. The chi-square 2 × 2 contingency test (Siegel 1956) was also employed in the analyses.

Results

TRACKING AND RECOVERY RECORD

Table 1 shows that the nine sockeye tracked in 1969 were followed from 2.0 to 32.3 hr (9.3 median) and from 3.8 to 43.8 km (23.4 median). The nine in 1970 were tracked from 4.0 to 66.6 hr (9.8

TABLE 1. Individual statistics of sockeye salmon tracked along the British Columbia coast in 1969 and 1970.

Sockeye no.	Total length (*mm*)	Duration in time (PST)			Track duration (*hr*)	Track distance (*km*)	Mean course speed (*cm/sec*)
		Age-group	Captivity (*hr*)	Date of release			
				1969 Tracks			
2	667	5_2	3.4	2156, 15 July	15.2	25.0	45.7
4	740	5_2	60.0	0704, 18 July	13.5	43.8	90.1
5	722	5_2	8.9	0556, 28 July	5.1	10.6	57.5
6	600	4_2	1.5	1758, 28 July	2.0	5.1	70.8
7	672	4_2	15.2	0741, 29 July	22.7	32.4	39.7
8	720	5_2	132.9	0953, 2 Aug.	32.3	39.4	33.8
9	731	5_2	3.7	1641, 4 Aug.	6.7	7.9	32.8
10	643	4_2	23.8	1247, 5 Aug.	7.5	16.2	60.0
11	588	4_2	39.7	0704, 10 Aug.	9.3	23.4	69.8
				1970 Tracks			
12	690	5_2	0.6	1305, 13 July	6.1	11.5	52.3
13	650	5_2	0.5	1135, 15 July	28.6	59.7	58.0
14	600	4_2	4.5	1330, 20 July	6.2	20.7	92.6
15	580	4_2	0.9	0810, 21 July	9.8	35.1	99.3
17	620	4_2	77.5	1430, 23 July	66.6	130.8	54.6
18	618	4_2	2.8	1107, 2 Aug.	29.9	60.0	55.8
19	615	4_2	49.3	1321, 6 Aug.	21.1	38.4	50.5
20	659	4_2	125.8	1405, 7 Aug.	5.5	13.5	68.3
21	640	5_2	155.4	1946, 8 Aug.	4.0	13.1	90.9

median) and from 10.5 to 130.8 km (35.1 median). Only one sockeye carrying a transmitter (1970) and one with an external clip (1969) were recovered. The former was processed beyond identification in a local fish cannery; the latter, which was initially captured and released with sockeye 9, was recovered 4 days after release at the mouth of the Skeena River, a direct distance by water of 87 km SSE from the release point. The minimum average speed required to make the trip was 24 cm/sec. The salmon tracked in 1969 were 4_2 and 5_2 sockeye and averaged 676 mm total length; those in 1970 were mainly 4_2 sockeye and averaged 630 mm.

TERMINATION OF TRACKS

The tracks were terminated for a variety of reasons. The most frequent reason was rough seas (No. 6, 10–13, 21). Some were lost when the tracking vessel stopped for current measurements (8, 9, 20). Others were lost because of equipment failure (3, 7, 16), logistic problems (4, 17), signal range reduction in shallow water (2, 5, 15, 19), and proximity of commercial fishing gear (14, 18).

DIRECTIONALITY

Of the six sockeye (No. 6–11) released near their points of capture north of Dundas Island in 1969, four fish showed a noticeable northerly component in their movements (Fig. 1). Five of the six also showed a westerly component in the terminal segments of the tracks. In addition, all three sockeye that were displaced to more open water (No. 2, 4, 5) swam north or west after release. The three fish (2, 7, 11) that changed direction upon nearing land (along the coast of Kanagunut Island) turned northwest, and not southeast. Sockeye 8 was an exception to the general movement pattern north and west. It covered about 39 km in a southeasterly direction during a 32-hr period.

In contrast to the 1969 track record, the pattern of movement following release in 1970 was to the east and south (Fig. 2). Five of the eight sockeye released north of Dundas Island in 1970 swam south after clearing the northern shore of the island. Only two fish (12, 21) showed a predominant north or west component in the overall track. The one sockeye (13) captured and released at Hogan Island near the mouth of Portland Inlet swam south when released.

Similarities in the swimming directions of salmon 17, 18, and 19 in 1970 deserve separate mention. All three fish proceeded east from Dundas and then turned south. Later, all three proceeded east again across the Main Passage; and still later, turned north (not south) along the B.C. coast toward

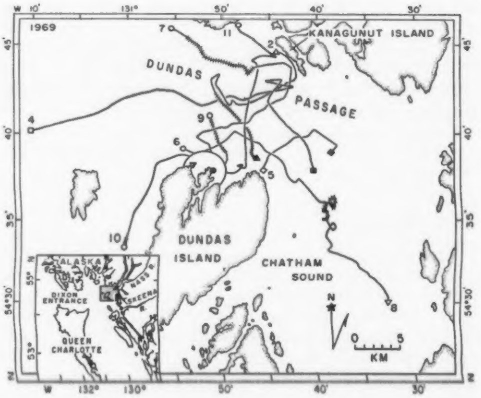

FIG. 1. Migratory courses of sockeye salmon bearing ultrasonic transmitters in 1969. Release points are indicated by solid symbols; final detection points by open (matching) symbols. The large circle north of Dundas Island encloses the capture area for all fish. Release points of nondisplaced fish appear within this circle; those of displaced fish, outside the circle. Five fish (6, 7, 9, 10, 11) were released at one release point (the small solid circle within the capture area); one fish, at each of the others. Course segments within the circle were omitted for greater clarity. In most cases these segments could be represented by straight lines between the release points and the corresponding courses at the circle periphery.

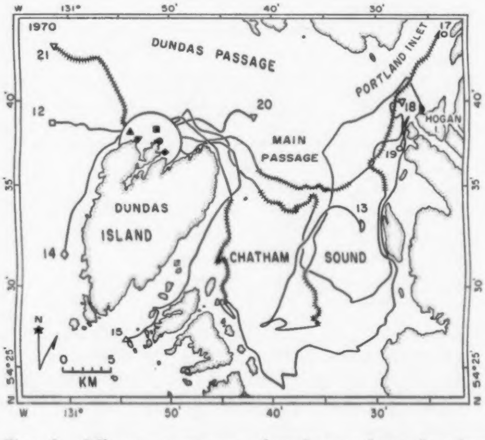

FIG. 2. Migratory courses of sockeye salmon bearing ultrasonic transmitters in 1970. See explanation in Fig. 1. Sockeye 13 was not displaced; it was captured and released next to Hogan Island. Three fish (18, 20, 21) were released at one release point (inverted triangle); two fish (17, 19), at another (small circle); and one fish, at each of the other four. Note that the course of sockeye 17 continues into Portland Inlet.

Portland Inlet. One fish continued up the Inlet (Fig. 3). All course changes to the north began in open water (3–4 km from land) that was greater than 100 m deep.

No obvious correlation between course directionality and age or size of the sockeye could be found for the 2 years.

SWIMMING SPEED

For both years a distinct diel cycle of swimming speed was observed (Fig. 4). In 1969 the maximum mean speed values for a 30-min period occurred around 1300 hr and, to a lesser extent, at 1900 hr. The minimum mean values occurred around 2400 hr. In 1970 the maximum and minimum values occurred at about 1500 and 0300 hr, respectively. The periods of greatest change in speed occurred around sunrise and sunset, about 0400 and 2000 hr.

The 30-min, mean speed values (48 in number for the 24-hr period) averaged 46 cm/sec (22–80 cm/sec) in 1969 and 59 cm/sec (24–90 cm/sec) in 1970. For individual fish, the maximum speed for a 30-min interval was 133 cm/sec in 1969 and 170 cm/sec in 1970. The corresponding minimum speeds for the 2 years were 4.9 cm/sec and 5.8 cm/sec. Clearly, the majority of the swimming speeds were well above the 28.6 cm/sec average current velocity measured during this study. However, the slowest mean values of swimming speed were similar to the average current velocity (Fig. 4), suggesting the possibility that some of the sockeye may have been drifting during the night.

The swimming speeds in 1969 were obviously slower than those in 1970. The lower average in 1969 was not the result of a higher frequency of night observations, since the frequency of night values in 1969 (23%) was actually lower than in 1970 (28%).

The cyclic nature and individual variation of swimming speed is evident in the records of the four sockeye that were tracked for periods longer than 24 hr (Fig. 5). One notable departure from the normal pattern occurred in the record of sockeye 17 during the second and third 24-hr periods. The cyclic nature seemed to be totally obscured, with perhaps a progressive reduction in speed throughout the time period. This abrupt change in pattern corresponds with the entrance of the fish into Portland Inlet (Fig. 3), a long slender bay subject to more pronounced tidal currents than in the more open waters of Chatham Sound.

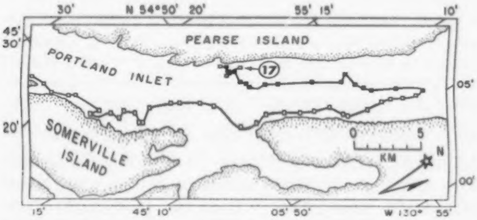

FIG. 3. The course of sockeye 17 in 1970 extending into Portland Inlet. The squares represent the original position fixes. Solid squares indicate night positions. The final detection point is indicated by the arrow that also encloses the sockeye number.

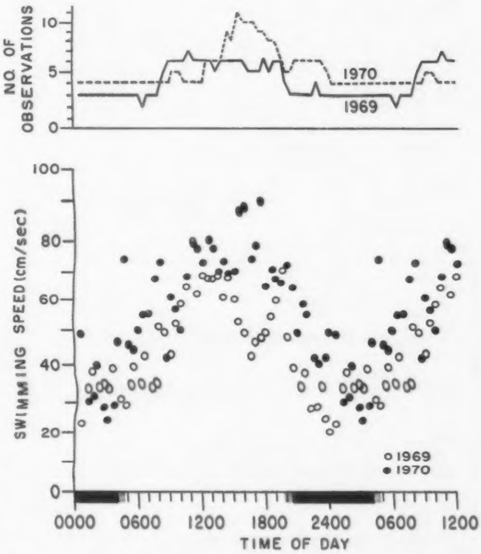

FIG. 4. Diel pattern of swimming speed for sockeye carrying ultrasonic transmitters in 1969 and 1970. Number of observations and corresponding mean are shown for each 30-min interval of the day. Means from 0000 to 1200 hr are used again for the 2400- to 3600-hr period to show more clearly the trend at 2400.

The speeds were also considered relative to the proximity of land (Table 2). There was no apparent correlation between swimming speed and distance within or beyond 2 km from land. For example, of the four course records with average speeds greater than 90 cm/sec, two were close to land (14, 15) and two were in open water (4, 21).

ANGULAR CHANGE

As with swimming speed, a diel pattern in the magnitude of angular change appeared. Unlike the speed pattern, the turning angles became progressively smaller from about 0700 to 2000 hr, and rather abruptly increased after dark (Fig. 6). From 2000 to 0700 hr little regularity was apparent except

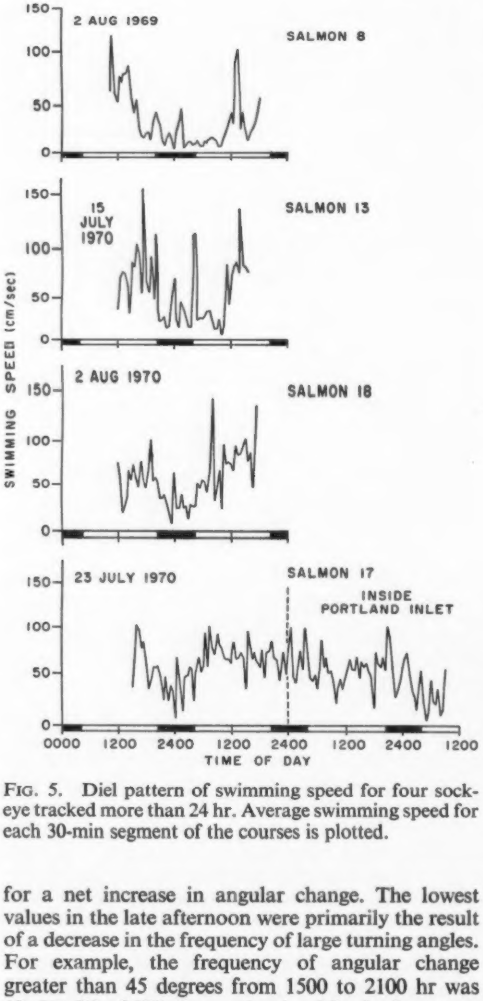

FIG. 5. Diel pattern of swimming speed for four sockeye tracked more than 24 hr. Average swimming speed for each 30-min segment of the courses is plotted.

for a net increase in angular change. The lowest values in the late afternoon were primarily the result of a decrease in the frequency of large turning angles. For example, the frequency of angular change greater than 45 degrees from 1500 to 2100 hr was 12.6% (22 of 175 observations), while the frequency of angular change greater than 45 degrees at other times of the 24-hr period was 23.2% (84 of 363 observations). The frequency difference was greater than would be predicted by chance ($\chi^2 = 7.65$, $P < .01$). Correlation of the mean angular change and swimming speed data is poor. The larger angular changes occurred both with low speed (at night) and high speed (late morning) estimates.

TABLE 2. Swimming speed relative to the proximity of land for those course records in 1969 and 1970 having five or more intervals for the calculation of the mean speeds.

	Distance from land			
	> 2 km		< 2 km	
Sockeye no.	No. of intervals	Mean speed (*cm/sec*)	No. of intervals	Mean speed (*cm/sec*)
		Daytime		
7	20	47.7	8	32.3
11	9	83.2	8	71.0
12	6	41.9	5	56.5
17	9	70.9	36	70.0
18	18	63.8	24	68.3
19	10	59.0	14	60.5
20	5	76.9	5	66.8
		Night time		
7	7	44.9	9	28.7
17	12	48.2	10	45.2

The angular change data for the individual courses over 24 hr in duration show the reduced number of course changes in the late afternoon (Fig. 7). As in the analysis of swimming speed, track 17 conforms to the general diel pattern for only the first day of tracking. The large turning angles during the second and third 24-hr periods (in Portland Inlet) are essentially restricted to the morning hours just after sunrise. The large angular changes normally occurring during the night are lacking.

Correlation of the angular change and swimming speed data improves at the level of the individual records (compare Fig. 5 and 7). An inverse relation is noticeable at times, particularly for salmon 8 and 13 which were tracked mostly in open water.

Discussion

The most conspicuous difference between the tracks for the 2 years was the north and west trend in 1969 and the south and east trend in 1970. Previous tagging–recovery studies indicated that a general southerly movement toward the home river systems was to be expected from sockeye salmon captured around Dundas Island. One study showed that, of the sockeye recovered after being tagged along the southeast coast of Alaska, 31.6% were retrieved from northern British Columbia waters (Aro and McDonald MS 1968). Of those recovered after being tagged in northern B.C. waters, only 2.1% were found along the southeast coast of Alaska.

In accordance with this southerly swimming direction, the majority of the sockeye used for our tracking were initially expected to be headed for

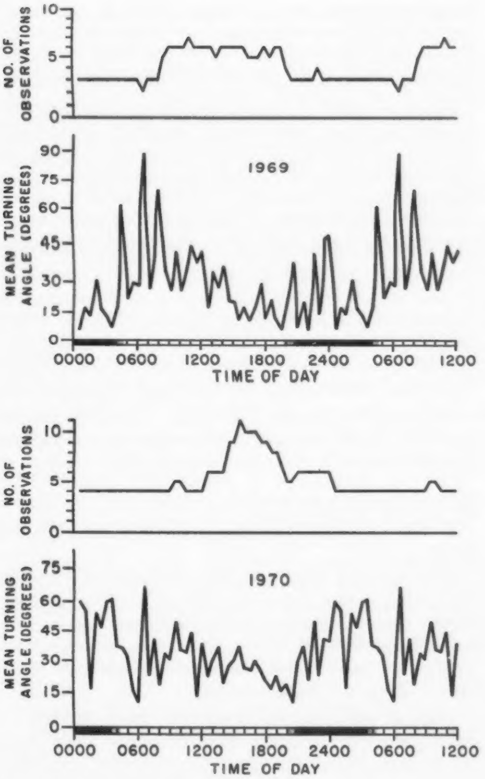

FIG. 6. Diel pattern of turning angle for sockeye carrying ultrasonic transmitters in 1969 and 1970. Number of observations and corresponding angular mean are shown for each 30-min interval of the day for both years. Means from 0000 to 1200 hr are used again for the 2400- to 3600-hr period.

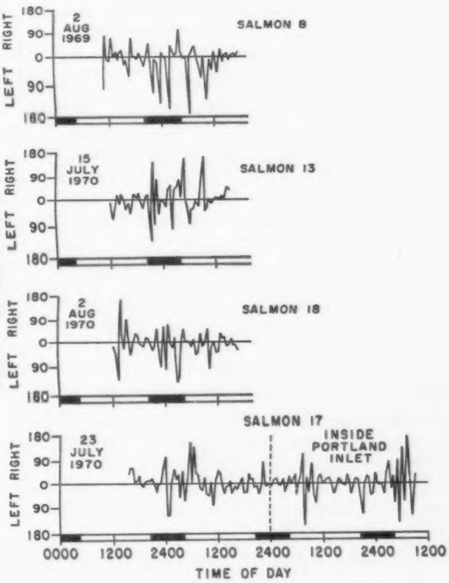

FIG. 7. Diel pattern of turning angle for four sockeye tracked more than 24 hr. Angular mean for each 30-min segment of the courses is plotted.

the Skeena River system. Both the general course trend in 1969 and the northward swimming direction along the east side of the Main Passage in 1970 (sockeye 17, 18, 19) suggested alternative destinations as well. Information from a third tagging–recapture study, in which 135 of 659 tagged sockeye were recaptured, indicated that sockeye in the Main Passage close to the mouth of Portland Inlet were mainly associated with the Nass River system (65%), while smaller percentages were associated with Alaskan rivers (20%) and the Skeena River (10%) (Williamson 1927). These data indicate that a large percentage of Nass River sockeye occur in the area just northeast of Dundas Island and, hence, that some Nass River salmon may have been used for tracking. One explanation, then, for the disparity in course direction within and between the years could be the difference in home river affiliation of the salmon that were tracked.

Another study suggests that some of the tracked salmon may have been affiliated with the Nass and Alaskan river systems. According to Neave (1964), several sockeye demes belonging to British Columbia and Alaska approach their respective coastal river systems in a rather direct course from the open ocean. Assuming that the sockeye north of Dundas Island were arrivals from the west through Dixon Entrance, a local three-way segregation of sockeye bound for the Skeena, Nass, and Alaskan river systems would be expected in an area encompassing much of Dundas Island. Thus, those sockeye tracked north and northwest of Dundas might be Alaskan salmon; those tracked eastward, Nass River salmon; and those tracked south and southwest, Skeena River salmon. When the course data are viewed as representing this segregation, the degree of apparent inconsistency in direction of movement from the release areas is considerably reduced. The difference in course direction between the 2 years, then, may have resulted from tracking records for a larger percentage of Alaskan sockeye in 1969, and of Nass River sockeye in 1970.

Additional evidence suggests that salmon 17 in 1970, and salmon 18 and 19 by virtue of course similarity, were probably Nass River sockeye. Skeena River salmon normally require 4–5 days to reach the Skeena River from the north shore of Dundas Island (Aro and McDonald MS 1968). Sockeye 17 nearly 3 days after release was 30 km farther from the Skeena River, making the total direct distance by water about 120 km. Only by swimming the most direct course at an average speed of 70 cm/sec could have sockeye 17 reached the Skeena in 5 days. Such movement would be quite unlikely.

The swimming speeds recorded for the sockeye of both years formed a typical diurnal rhythm of activity. Previously, this movement pattern was not known (Neave 1964), and only occasional reference was made regarding day or night movements (Hasler 1966; Royce et al. 1968). Some speed reduction at night was shown for chinook salmon in a river system (Johnson 1960). Daily periods of movement for salmonids have been speculated to be 8 hr (Neave 1964) and 14 hr (Harden-Jones 1968) in duration.

The only departure from the daily rhythm of swimming speed in this study was that for sockeye 17 in Portland Inlet. The apparent cessation of rhythm observed could have resulted from a combination of effects including the bidirectional current flow in the Inlet, the close proximity of the sockeye to its presumed home river (Nass), and the tendency, as postulated by Hasler (1966) and Kleerekoper (1969), of migrating salmon to swim against currents laden with home stream waters and to swim locally or drift with currents not carrying the home odors. Thus, sockeye 17 could have been induced to swim at night by ebb tide currents containing Nass water and to have been inhibited from swimming during the day by flood tide currents without the home river odors.

The swimming speeds were generally comparable to the values obtained by others for salmonids. Our values (5–170 cm/sec; 53 cm/sec average) obtained for sockeye in coastal areas were similar to the values (4–180 cm/sec; 49 cm/sec average) given for chinook salmon in the Columbia River (Johnson 1960). However, the similarity in speeds could be misleading since the average speed for sockeye included night estimates of comparatively slow speeds while the average speed for chinook did not include night values. Neither speed record was close to the 660 cm/sec maximum value recorded in a 26- m experimental channel for chinook and silver salmon (Weaver 1963).

When used to predict the distance that could have been covered in a day, the average sockeye speeds gave distance values that were comparable to previous estimates. The 53 cm/sec average speed over a 24-hr period represents a distance capability of 46 km (25 nautical miles) per day, an ability almost matching the 30 nautical miles/day minimum required to account for the tagging–recapture records of sockeye at sea (Neave et al. MS 1962; Hartt 1962). Ocean currents could add 1–10 nautical miles/day (Harden-Jones 1968) to the 25 to give the minimum daily rate required. The somewhat lower speeds for the tracked sockeye may represent responses to the coastal environment, or perhaps, to possible transmitter or handling effects.

The reason for the difference in swimming speed between the 2 years is not known. Possible explanations could include: 1) differences in home river affiliation between the years, 2) differences between the areas where most of the tracking took place (Dundas Passage in 1969 and Chatham Sound in 1970), 3) differences in size or age of the sockeye (the smaller and younger salmon being tracked in 1970), 4) differences in transmitter weight (38 g in 1969 and 20 g in 1970), or 5) possible differences in weather or oceanographic conditions between the years.

The lack of any apparent correlation between swimming speed and proximity of land for sockeye differs from observations on cutthroat trout (McCleave and Horrall 1970). The latter species, when swimming near shore, increases its average speed from about 23 to 37 cm/sec.

Slightly less obvious than the daily rhythm of swimming speed was the daily pattern in magnitude of turning angle. The periodic afternoon reduction in large turning angles suggests the operation of orientation mechanisms—assuming that this reduction is indicative of more direct, and presumably adaptive, movement. It may be that references for accurate orientation at night are restricted (hence, the slower speeds and the increasing number of large turning angles after dark), and that a certain degree of orientation must be reestablished during the next day. The increasing swimming speeds and large and gradually decreasing turning angles in the morning would reflect this reorientation process. The most "direct" movements around dusk for these adult salmon correspond well with the time of greatest activity of seaward migrating sockeye smolts (Groot 1965). That the opposing migrations of this species may involve the use of similar cues is an interesting possibility.

Acknowledgments

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C. Groot of the Fisheries Research Board of Canada and P. Murray, I. Todd, and J. Buxton of the Canadian Department of Fisheries and Forestry made our operation at Prince Rupert a successful experience. The cooperation of J. Johnson of the National Marine Fisheries Service and the assistance of J. Hildreth, J. Robinson, A. Scholz, and T. Stewart, students at the University of Wisconsin, is gratefully acknowledged. Discussions with E. Gardella, and the figure preparation of C. Hughes, facilitated the preparation of the manuscript. This project received financial support from N.S.F. grant GB7616 to A. D. Hasler, and from the Fisheries Research Board of Canada.

Aro, K. V., and J. McDonald. MS 1968. Times of passage of Skeena river sockeye and pink salmon through the commercial fishing area. Fish. Res. Board Can. MS Rep. Ser. (Biol.) 984: 169 p.

Batschelet, E. 1965. Statistical methods for the analysis of problems in animal orientation and certain biological rhythms. Amer. Inst. Biol. Sci. Monogr. 1: 57 p.

Clutter, R., and L. Whitesel. 1956. Collection and interpretation of sockeye salmon scales. Int. Pac. Salmon Fish. Comm. Bull. 9: 159 p.

Foerster, R. 1968. The sockeye salmon, *Oncorhynchus nerka*. Fish. Res. Board Can. Bull. 162: 422 p.

Gallepp, G. MS 1970. The effects of negative buoyancy on the behavior of the bluegill, *Lepomis macrochirus* (Rafinesque). M.S. Thesis. Univ. of Wisconsin, Madison, Wis. 51 p.

Groot, C. 1965. On the orientation of young sockeye salmon (*Oncorhynchus nerka*) during their seaward migration out of lakes. Behav. Suppl. 14: 198 p.

Harden-Jones, F. 1968. Fish migration. St. Martin's Press, New York, N.Y. 325 p.

Hartt, A. 1962. Movement of salmon in the North Pacific Ocean and Bering Sea as determined by tagging 1956–1958. Int. N. Pac. Fish. Comm. Bull. 6: 157 p.

Hasler, A. D. 1966. Underwater guideposts. University of Wisconsin Press, Madison, Wis. 155 p.

Hasler, A. D., R. Horrall, A. Stasko, and A. Dizon. 1970. Orientation cues and tracking of migrating salmonid fishes. Proc. Nat. Acad. Sci. 66: 241–242.

Johnson, J. 1960. Sonic tracking of adult salmon at Bonneville Dam, 1957. U.S. Fish Wildl. Serv. Fish. Bull. 176: 471–485.

1971. Fish-borne transmitters. Underwater Telem. Newsl. 1: 1–4.

Kleerekoper, H. 1969. Olfaction in fish. Indiana University Press, Bloomington, Indiana. 222 p.

Madison, D., and A. D. Hasler. 1971. Recent advances in salmon orientation. Amer. Zool. 11: 629–630.

McCleave, J., and R. Horrall. 1970. Ultrasonic tracking of homing cutthroat trout (*Salmo clarki*) in Yellowstone Lake. J. Fish. Res. Bd. Canada 27: 715–730.

McCleave, J., L. Jahn, and C. Brown. 1967. Miniature alligator clips as fish tags. Progr. Fish-Cult. 29: 60–61.

Neave, F. 1964. Ocean migrations of Pacific salmon. J. Fish. Res. Bd. Canada 21: 1227–1244.

Neave, F., J. Manzer, H. Godfrey, and R. LeBrasseur. MS 1962. High-seas salmon fishing by Canadian vessels in 1962. Fish. Res. Board Can. Rep. 593: 59 p.

Rich, W., and F. Morton. 1929. Salmon tagging experiments in Alaska, 1927 and 1928. U.S. Bur. Fish. Bull. 45: 1–23.

Rich, W., and A. Suomela. 1927. Salmon tagging experiments in Alaska in 1926. U.S. Bur. Fish. Bull. 43: 71–104.

Royce, W., L. Smith, and A. Hartt. 1968. Models of oceanic migrations of Pacific salmon and comments on guidance mechanisms. U.S. Fish Wildl. Serv. Fish. Bull. 66: 441–462.

Sehdev, H., J. McBride, and U. Fagerlund. 1963. 2-Phenoxyethanol as a general anesthetic for sockeye salmon. J. Fish. Res. Bd. Canada 20: 1435–1440.

Siegel, S. 1956. Nonparametric statistics. McGraw-Hill, New York, N.Y. 312 p.

Stasko, A. 1971. Review of field studies on fish orientation. *In* H. Adler [ed.] Orientation: sensory basis. Ann. N.Y. Acad. Sci. 188: 12–29.

Verhoeven, L., and E. Davidoff. 1962. Marine tagging of Fraser River sockeye salmon. Int. Pac. Salmon Fish. Comm. Bull. 13: 132 p.

Weaver, C. 1963. Influence of water velocity upon orientation and performance of adult migrating salmonids. U.S. Fish Wildl. Serv. Fish. Bull. 63: 97–122.

Williamson, H. 1927. Pacific salmon migration: Report on the tagging operations in 1925. Contrib. Can. Biol. Fish. 3: 267–306.

1929. Pacific salmon migration: Report on the tagging operations in 1926 with additional returns from the operations of 1925. Contrib. Can. Biol. Fish. 4: 455–470.

Mobilization of Mercury from Sediments into Guppies (*Poecilia reticulata*)

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GILLESPIE, D. C. 1972. Mobilization of mercury from sediments into guppies (*Poecilia reticulata*). J. Fish. Res. Bd. Canada 29: 1035–1041.

Guppies (*P. reticulata*) were exposed in aquaria to aerobic and anaerobic sediments to which various forms of mercury were added and to sediments from two sites of industrial pollution. Whole body levels of total mercury (atomic absorption analysis) in these fish were used as a measure of mobilization of mercury from these sediments. Spot checks for methylmercury were carried out at intervals during the tests. Under aerobic conditions there was little mobilization of mercury from sediments to which mercuric chloride or sulphide had been added but total mercury concentrations rose rapidly in fish exposed to sediments containing metallic mercury.

The proportion of methylmercury in fish reached maxima of 30% for metallic mercury, 40% for mercuric chloride, and 45% for mercuric sulphide. In anaerobic sediments, total mobilization was low and only mercuric chloride was significantly methylated (40% of the total in the fish).

Both mobilization and methylation were proportionately greater in industrial sediments with a low mercury content than in sediments with a higher mercury content. Enrichment of sediments with lignosulphonate showed no real effects aerobically, possibly because of the chelation properties of the preparation used. Anaerobically, lignosulphonate stimulated methylation of mercury.

The levels of mercury and methylmercury found in fish are consistent with data from nature. Some of the implications of the results are discussed.

GILLESPIE, D. C. 1972. Mobilization of mercury from sediments into guppies (*Poecilia reticulata*). J. Fish. Res. Bd. Canada 29: 1035–1041.

L'auteur a exposé des guppy (*P. reticulata*) en aquarium à des sédiments aérobies et anaérobies auxquels il avait ajouté du mercure sous diverses formes, et à des sédiments provenant de deux sites de pollution industrielle. La concentration de mercure total dans le corps entier du poisson (analyse par absorption atomique) a servi à mesurer la mobilisation du mercure des sédiments. Une vérification par touches du mercure-méthyl a été faite par intervalles au cours des essais. Dans des conditions aérobies, il n'y a que très peu de mobilisation de mercure des sédiments auxquels on a ajouté du chlorure ou du sulfure mercurique, mais la teneur en mercure total augmente rapidement dans les poissons exposés aux sédiments contenant du mercure métallique.

La proportion de mercure-méthyl dans les poissons atteint des sommets de 30% pour le mercure métallique, 40% pour le chlorure et 45% pour le sulfure mercurique. Dans les sédiments anaérobies, la mobilisation totale est lente, et seul le chlorure mercurique subit une méthylation significative (40% du total dans le poisson).

La mobilisation et la méthylation sont toutes deux proportionnellement plus élevées dans le cas de sédiments industriels à faible teneur en mercure que dans le cas de sédiments à forte teneur. L'enrichissement des sédiments au lignosulfonate n'a aucun effet réel dans des conditions aérobies, possiblement à cause des propriétés de chélation de la préparation utilisée. Dans des conditions anaérobies, le lignosulfonate stimule la méthylation du mercure.

Les niveaux de mercure et de mercure-méthyl observés dans les poissons concordent avec les données cueillies dans la nature. L'auteur examine quelques-unes des implications de ces résultats.

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MERCURY, while not a major mineral in the earth's crust, is fairly widespread in low-grade deposits (Jonasson 1970) and can be transported after weathering and erosion into the sediments of lakes and streams. Interconversion of mercurials by chemical and microbiological processes results in accumulation of mercury in fish and other aquatic organisms (Matida and Kunada 1969; Jernelov 1968a, b, 1969). Methylmercury compounds, which are of interest because of their predominance in fish, presumably arise from microbial action on inorganic or other organic mercury compounds in sediments (Tonomura 1969).

Mercury apparently enters fish either via the food chain and/or by direct absorption through the gills. Swedish workers (Jernelov 1970) seem to favor the second route as being more important, though no definitive experiments have been carried out to evaluate the relative importance of these routes under various conditions.

In Canada, high concentrations of mercury in fish have been associated with discharge of elemental or inorganic mercury (as the chloride) from chlor-alkali plants (Bligh MS 1970). In Sweden, chlor-alkali effluents were implicated in high mercury levels in fish in some areas, but the highest concentrations seemed to be associated with the presence of fiber deposits containing phenyl mercuric acetate which had been used as a preservative in the pulp industry (Johnels et al. 1967; L. Hannerz personal communication 1968).

Preliminary experiments using mercurials added to sediments (Gillespie and Scott 1971) showed a relatively rapid transfer of mercury from sediments to fish. The present experiments were undertaken in order to extend these observations.

Materials and Methods

The aerobic aquarium system described previously (Gillespie and Scott 1971) was used in these experiments. Unless noted all procedures and conditions were the same. Metallic mercury was dispersed by sonic oscillation as had been done in the previous experiment with mercuric sulphide. Sediments from the St. Clair River were supplied by Mr John Neil of the Ontario Water Resources Commission and those from the Saskatchewan River by Dr J. F. Uthe of the Freshwater Institute. Cinnabar ore was obtained from Consolidated Mining and Smelting Company. Total mercury content of whole fish was measured by the flameless atomic absorption method of Uthe et al. (1970). Methylmercury analyses were carried out using a modified Westöö procedure (Solomon and Uthe 1971). Spot analyses for methylmercury were performed at intervals throughout the experiment. Two

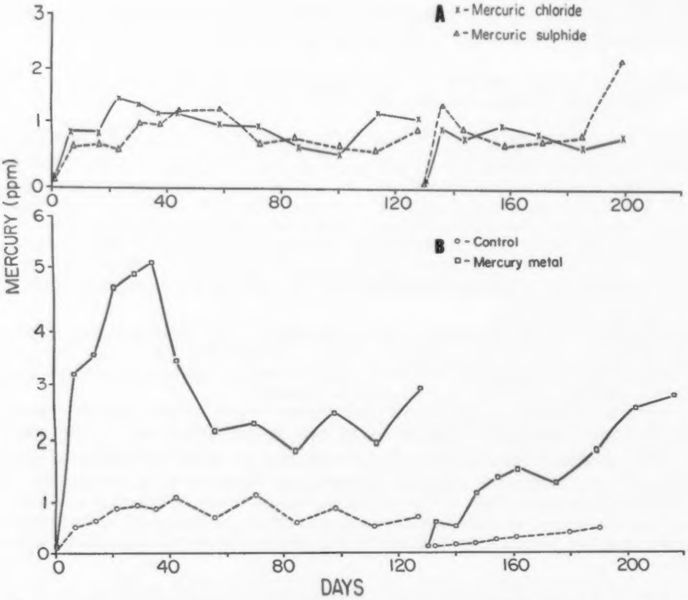

FIG. 1. Mercury levels in guppies exposed to sediment with added mercurials. Mercury added to control sediment (Delta marsh, 0.1 ppm mercury) at 50 ppm level (dry-weight basis). Each point is the average for five fish.

whole fish were used for each determination. Total and methylmercury levels are expressed as ppm (parts per million) mercury, on a wet weight basis for fish and dry weight of sediments.

Sediments for anaerobic mobilization (250 gm each) were placed in quart mason jars and filled to the top with tap water. Coarse nylon mesh was cemented across the top of the jars and the tops were capped. The jars were let stand 24 days at room temperature to become anaerobic and placed in the rear corner of aquaria set up in the same way as the aerobic experiments. The metal caps were removed after the jars were submerged, and fish placed in the aquaria immediately. The jars were 17 cm deep and the sediments settled to a compacted mass of 5–6 cm, with a loose layer of approximately 0.5 cm on top. It was presumed that the nylon mesh caps would inhibit oxygen entering the jars by convection and that bacterial action in the loose layer would result in anaerobic conditions in the bulk of the sediment. Oxygen probe measurements using an uncapped jar showed that when the water in the tank was saturated with oxygen the water 5 cm from the top of the jar was at 75% oxygen saturation.

Control sediment and sediment to which mercury compounds were added, came from the Delta Marsh at the south end of Lake Manitoba and contained 0.1 ppm mercury. Additions were made to achieve a 50 ppm mercury level on a dry-weight basis. A second control sediment from Lake 227 of the Freshwater Institute Experimental Lakes Area, containing 0.15 ppm mercury, was also used.

EXPERIMENTAL RESULTS

It was planned to run the experiments for over 100 days after the addition of fish. In most cases a second addition of fish was necessary because of heavy mortalities early in the experiment. The major cause of mortality was the sick condition of the fish in two shipments. In the case of the St. Clair River sediments, an oily contaminant which was not completely removed by filtration and air-drying proved to be toxic to guppies. Mercury analyses of dead fish showed levels only slightly above the zero time figures; thus death did not result from acute mercury poisoning.

For these reasons a second lot of fish was added to all tanks, including those which had run successfully for over 100 days.

ARTIFICALLY CONTAMINATED SEDIMENTS

Fish exposed to Delta Marsh sediment with added mercuric sulphide showed no difference in mercury levels (Fig. 1A) from fish exposed to control sediment. Spot checks for methylmercury (Table 1) indicated somewhat higher proportions of this form in the fish exposed to mercuric sulphide, but methylmercury represented less than half the total mercury.

In the second group of fish exposed, both total and methylmercury were higher in the fish exposed to sediment containing mercuric sulphide than in those exposed to control sediment.

Results obtained with mercuric chloride were similar to those obtained with mercuric sulphide. In the previous experiment (Gillespie and Scott 1971) using mercuric sulphide or chloride, the experimental fish showed total mercury levels higher than control fish in a relatively short time. The sediment used in the former experiments was high in organic matter, which would stimulate microbial activity and enhance mobilization of mercury compounds.

TABLE 1. Total and methylmercury content of guppies exposed to sediments with added mercury.[a]

Sediment	Days exposure	Series	ppm mercury Methyl	ppm mercury Total
Delta Marsh	28	1	0.1	1.0
(Control)	125	1	0.15	0.7
(0.1 ppm)	45	2	0.1	0.4
Metallic	28	1	0.1	4.8
Mercury	125	1	0.14	2.9
(50 ppm)	45	2	0.34	1.4
	88	2	0.92	2.7
	70	An	0.1	0.65
Mercuric	97	1	0.46	1.0
Chloride	35	2	0.34	0.8
(50 ppm)	70	An	0.23	0.59
Mercuric	28	1	0.1	1.0
sulphide	125	1	0.4	0.9
(50 ppm)	35	2	0.32	0.7
	77	2	0.24	(1.35)
	70	An	0.09	0.81

[a]Figures in parentheses indicate total mercury level at the last date for which it was determined; An, data from experiment using anaerobic sediments; series, refers to first and second additions of fish; total mercury values from the average of five fish; methylmercury values from single large fish or two fish pooled for analysis.

Metallic mercury produced a different result. High mercury levels appeared in the fish in a short time (Fig. 1B). The levels dropped and then showed a slow rise. After the second addition of fish the mercury levels in these fish showed a continuous rise. In the first series methylmercury levels (Table 1) were similar to those in control fish; in the second series levels rose fairly rapidly but were proportionately similar to the control fish.

ST. CLAIR RIVER SEDIMENTS

The decreasing mercury contents in these sediments correlate with increasing distance downstream from the source of mercury pollution, which was effluent from a chlor-alkali plant, and the mercury probably entered the sediment as chloride and in metallic form. A sample of the high-level sediment (120 ppm mercury) was enriched with 0.5% (dry-weight basis) of a lignosulphonate (Orzan AH-3, courtesy of Crown Zellerbach Ltd.). This substance affects the texture of sediments, is a chelating agent, and to some extent a fertilizer.[1] It was used primarily to test the effect of nutrient enrichment on mobilization. Fish exposed to these sediments (Fig. 2) showed an increase in mercury level and then a drop similar to that found in the experiment with metallic mercury. The height of the rise corresponded to the total mercury content of the sediment but was reduced considerably by addition of lignosulfonate to the highly contaminated sediment. Because of toxic pollutants in the sediments, the first series of analyses was interrupted. A second batch of fish added here did not show the rapid rise and fall in mercury content, except with the high-level sediment. Methylmercury levels (Table 2) in the fish exposed to these sediments rose slowly but reached a high proportion of the total mercury in fish most rapidly in the low-level (9 ppm) sediment and after a longer time in the medium-level (40 ppm) sediment. Lignosulfonate enrichment of the sediment resulted in lower total mercury levels in the fish and a lower proportion of methylated mercury. The low (9 ppm) and medium (40 ppm) sediments produced relatively more total and proportionately more methylmercury in fish than did the high-level sediment. These sediments appeared to be more open in texture and to have a higher organic content than did the high-level sediment. Both of these factors would enhance microbial growth and thus mobilization. In addition the concentration of mercury in the high-level sediment may be inhibitory to microorganisms.

CINNABAR ORE

Several pieces of cinnabar ore ranging from 1 to 10 cm in their greatest dimension were placed in an aquarium without any sediment. The total mercury levels in some fish exposed to the ore (Fig. 3A) reached high levels (over 400 ppm) and varied widely. Near the end of the experiment the levels dropped and remained low. The fish nibbled at the exposed rock and probably ingested small particles of ore. At 47 days (run 1) eight fish were removed from the tank, divided into two groups of four, and eviscerated. The viscera from each group were pooled for mercury analysis, and the bodies were analyzed individually. The viscera in group 1 contained 310 ppm mercury and the bodies averaged 5.36 ppm (range 3.24–11.38 ppm). In the second group the figures were 245.6 ppm for the viscera and 6.64 ppm (range 2.11–20.6) for the bodies. The figures for body mercury were probably high, since only a crude removal of viscera could be effected from fish weighing 100–150 mg. Methylmercury values (Table 3) were low in these fish, especially in terms of the high total mercury content. These results show that, for this species at least, ingested mercury was not methylated in the intestinal tract to any significant extent.

SASKATCHEWAN RIVER SEDIMENTS

Two experiments were carried out with sediments obtained immediately downstream from a source of industrial pollution. One sediment contained 60 ppm mercury, the other 7 ppm mercury with addition of 0.5%

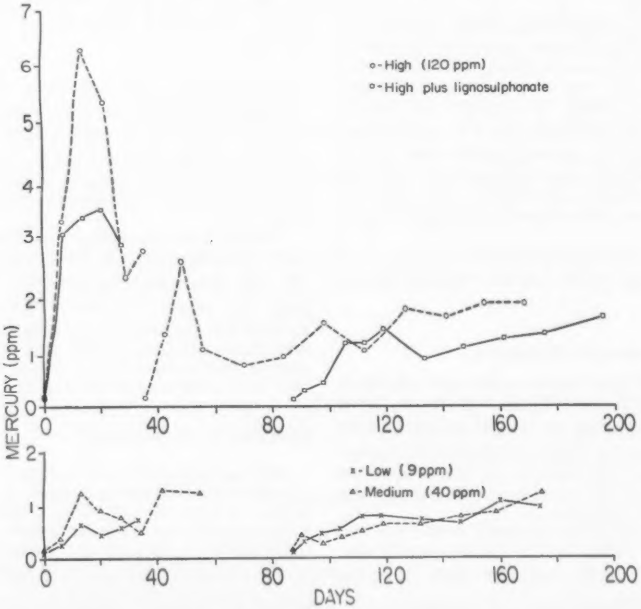

FIG. 2. Mercury levels in guppies exposed to sediments from the St. Clair River with added lignosulphonate.

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[1] Information bulletin from Crown Zellerbach Corporation Chemical Products Division, Camos, Washington.

TABLE 2. Total and mercury content of guppies exposed to sediments from the St. Clair River.[a]

Sediment	Days exposure	Series	ppm Mercury	
			Methyl	Total
St. Clair low (9 ppm)	35	1	0.3	0.7
	45	2	0.4	0.79
	60	2	0.3	0.72
	88	2	0.71	0.98
St. Clair medium (40 ppm)	84	1	0.39	(1.2)
	45	2	0.08	0.6
	88	2	1.31	(1.3)
St. Clair high (120 ppm)	45	2	0.23	1.8
	88	2	0.82	1.97
	70	An	0.06	0.69
St. Clair high (120 ppm) with lignosulphonate	84	1	0.15	(2.8)
	45	2	0.07	1.2
	88	2	0.3	1.49
	150	2	0.65	1.75
	70	An	0.31	0.60

[a]Figures in parentheses indicate total mercury level at the last date for which it was determined; An, data from experiment using anaerobic sediments; series, refers to first and second additions of fish; total mercury values from the average of five fish; methyl mercury values from single large fish or two fish pooled for analysis.

lignosulfonate (Fig. 3B). Exposure of fish to the high-level sediment produced a rise and then a fall in the mercury content of the fish in both the first and second tests. Methyl mercury (Table 3) again accounted for only a fraction of the total mercury. With the enriched sediment, total mercury levels in the fish rose gradually, finally exceeding those obtained from exposure to the high-level sediment.

Spot checks for methylmercury (Table 3) in the fish exposed to the low-level enriched sediment showed that it accounted for 80% or more of the total (Table 1). The experiment was designed so that any effect of enrichment would show more clearly by comparing an enriched sediment with an unenriched one from the same source containing about ten times the mercury concentration.

Interpreting the increased mobilization in the low-level sediment from the Saskatchewan River as resulting from nutrient addition is dubious when the data from the St. Clair River sediments are considered.

Data in Table 2 indicated that mercury in low level sediments (9 ppm) is more efficiently mobilized as methyl mercury than from those sediments containing a higher concentration (100 ppm) in the absence of enrichment. In fact lignosulfonate addition (to sediments high in mercury) seemed to inhibit mobilization, and possibly the chelating properties of the lignosulfonate were responsible.

ANAEROBIC MOBILIZATION

Sediments used in these tests were Delta control, Delta with $HgCl_2$, Hg, or HgS added, St. Clair high-level sediment, and St. Clair high-level plus lignosulfonate, and were subsamples from the same batches used for aerobic experiments. The first series of analyses were terminated at 35 days because of heavy mortalities in an unhealthy batch of fish. There was no rapid rise in mercury levels in fish exposed to sediments containing metallic mercury or to the St. Clair sediments, as occurred in the aerobic test. A steady increase in total mercury in the fish from 0.17 ppm at zero time to 0.8 ppm at 35 days occurred in the control series. No significant differences were found in the other fish except with the St. Clair River sediment, where the fish contained 1.5 ppm mercury at 35 days.

In the second experiment which continued for 70 days the mercury content of the fish rose from 0.08 ppm at zero time to 0.5 ppm at 14 days, with a gradual increase to 0.6–0.8 ppm at the end of the experiment.

Methylmercury analysis at the end of the second experiment (Tables 1, 2, 3,) showed only traces (0.1 ppm or less) present in fish from all tanks, except for the mercuric chloride series (40% of total = .23 ppm) and the St. Clair sediment plus lignosulfonate (50% of total = .31 ppm).

The results show that at least in these sediments anaerobic mobilization was very slow compared to the aerobic process. This was not unexpected in view of the relatively slow growth and metabolism of anaerobic as compared to aerobic microorganisms.

Discussion

Microorganisms undoubtedly play a large role in the conversion of mercury compounds in sediments. The important conversion under consideration here is the methylation of mercury, because it occurs in fish in methylated form to the extent of 80–100% of the total mercury. Methylmercury compounds have been shown to have high toxicity for humans, and the bacterial formation of these compounds has thus become an important question.

The present experimental results are somewhat different from those of Jernelov (1970), who reported 1–3 ppm of "methylmercury" taken up by guppies in 15 days at 25 C. The temperature difference might partially account for the rapid mobilization he obtained, but more likely the biological activity generated by the high organic content of the sediments he used was responsible.

The relative importance of anaerobic versus aerobic formation of "methylmercury" by bacteria has not yet been assessed. This is an important question since it has been proposed that mercury in sediments could be immobilized by burying them under 10 cm of fill (Jernelov 1969).

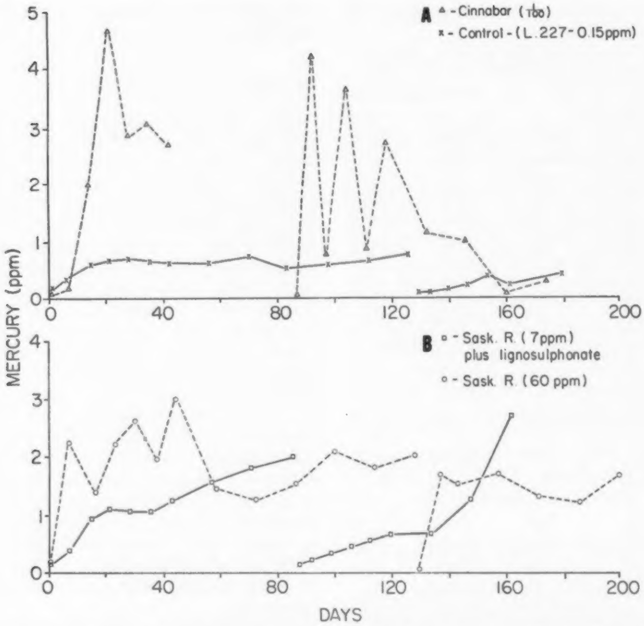

FIG. 3. Mercury levels in guppies exposed to cinnabar (A) and to sediments from the Saskatchewan River (B).

TABLE 3. Total and methylmercury content of guppies exposed to sediments from the Saskatchewan River and to cinnabar ore.[a]

Sediment	Days exposure	Series	ppm mercury	
			Methyl	Total
	28	1	0.1	2.5
Saskatchewan R.	125	1	0.6	2.0
high (60 ppm)	35	2	0.49	1.9
	77	2	0.32	(1.6)
Saskatchewan R. low (7 ppm)	74	1	2.43	2.1
plus lignosulphonate	45	2	0.63	0.7
Lake 227	126	1	0.15	0.7
(control)	140	1	0.92	0.8
(0.15 ppm)	45	2	0.11	0.35
Cinnabar	45	2	0.09	110
	89	2	0.28	32

[a]Figures in parentheses indicate total mercury level at the last date for which it was determined; series, refers to first and second additions of fish; total mercury values from the average of five fish; methyl mercury values from single large fish or two fish pooled for analysis.

Burying a sediment, especially one high in organic matter, would not stop anaerobic metabolism. The experiments of Wood et al. (1968) and Inamura et al. (1971) have been interpreted to mean that anaerobic methylation of mercury by methane bacteria is an important process in nature. This may be true but has not so far been demonstrated directly. The methyl cobalamines which were used in these experiments are common metabolites, and compounds of this class are excreted by aerobic and facultative bacteria. This mechanism could then be important aerobically as well as anaerobically and could occur as an incidental chemical reaction.

Anaerobic processes are generally slower than aerobic ones and the results from these experiments, which showed that aerobic mobilization is more rapid than anaerobic, are not surprising. The model system proposed by Landner (1971) involving the interruption of the transmethylation of cysteine and homocysteine by mercuric ion also involves a basic and widespread metabolic reaction that would presumably operate inside living cells. Again, the more rapid biosynthesis in aerobic conditions would favor more rapid aerobic mobilization of mercury.

A series of model experiments using a variety of sediments and mercury compounds under both aerobic and anaerobic conditions is required to elucidate the range of possibilities for microbial mobilization of mercury. Tonomura (1969) has indicated a complex series of changes in mercurials by bacteria, including reduction to metallic mercury. Such experiments can be misleading, since slightly alkaline solutions of glucose or normal bacterial media, which contain reducing groups, will cause the incidental reduction of mercuric chloride in other salts to metallic mercury (personal observation). The data in the present experiments showed that in the short term (100 days), forms of mercury other than "methylmercury" are a significant proportion of the total mercury load in fish. The situation in nature is that 80% or more of the total mercury in fish occurs as the methylated form. The data of Bache et al. (1971) showed that in lake trout the ratio of methylated to total mercury rises from around 0.3 for fish a year old to 0.8–1.0 for fish several years old.

These other forms of mercury, even though quantitatively small, could be important in terms of human health.

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BACHE, C. A., W. H. GUTENMANN, AND D. J. LISK. 1971. Residues of total mercury and methyl mercury salts in lake trout as a function of age. Science 172: 951–952.

BLIGH, E. G. MS 1970. Mercury and the contamination of freshwater fish. Fish. Res. Board Can. Freshwater Inst. MS Rep. 1088.

GILLESPIE, D. C., AND D. P. SCOTT. 1971. Mobilization of mercuric sulphide from sediment into fish under aerobic conditions. J. Fish. Res. Bd. Canada. 28: 1807.

HANNERZ, L. 1968. Experimental investigations on the accumulation of mercury in water organisms. Inst. Freshwater Res. Drottningholm Rep. 48: 120–176.

INAMURA, N., E. SUKEGAWA, S.-K. PAN, K. NAGAO, J.-Y. KIN, T. KWAN, AND T. UKITA. 1971. Chemical methylation of inorganic mercury with methyl cobalamin a Vitamin B_{12} analog. Science 172: 1248–1249.

JERNELOV, A. 1968a. A laboratory experiment regarding the conversion of mercury into its different forms of occurrence. Vatten 53–56. (Transl. by Transl. Bur. Dep. Secr. State No. 5430)

1968b. Vatten 465–468. (Transl. by Transl. Bur. Dep. Secr. State No. 5431)

1969. Mercury conversions and what we can do to affect them. Nord. Hyg. Tidskr. 50: 174–178. (Transl. by Transl. Bur. Dep. Secr. State No. 5432)

1970. Release of methyl mercury from sediments with layers containing inorganic mercury at different depths. Limnol. Oceanogr. 15: 958–960.

JOHNELS, A. G., T. WESTERMARK, W. BING, P. I. PERSSEN, AND B. SJOSTRAND. 1967. Pike (*Esox lucius*) and some other aquatic organisms in Sweden as indicators of mercury contamination in the environment. Oikos 18: 323–333.

JONASSON, I. R. 1970. Mercury in the natural environment. A review of recent work. Geol. Surv. Can. Pap. 70–57.

LANDNER, L. 1971. Biochemical model for the methylation of mercury suggested from methylation studies in vivo with *Neurospora crassa*. Nature 230: 452–453.

MATIDA, Y., AND H. KUNADA. 1969. Distribution of mercury in water, bottom mud and aquatic organisms of Minamata Bay, the river Agano and other water bodies in Japan. Bull. Freshwater Fish. Res. Lab. Tokyo 19: 73–92.

SOLOMON, J., AND J. F. UTHE. 1971. A rapid semimicro method for methyl mercury analysis in fish by gas chromatography. Mercury in the western environment. Abstracts of papers. Environmental Health Sciences Center. Oregon State University, Oreg.

TONOMURA, K. 1969. Action of mercury resistant bacteria on mercurials. Technocrat 4: 44–47.

UTHE, J. F., F. A. J. ARMSTRONG, AND M. P. STAINTON. 1970. Mercury determination in fish samples by wet digestion and flameless atomic absorption spectrophotometry. J. Fish. Res. Bd. Canada 27: 805–811.

WOOD, J. M., F. A. KENNEDY, AND C. G. ROSEN. 1968. Synthesis of methyl mercury compounds by extracts of a methanogenic bacterium. Nature 220: 173–174.

Vital Statistics, Biomass, and Seasonal Production of an Unexploited Walleye (*Stizostedion vitreum vitreum*) Population in West Blue Lake, Manitoba

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The population of walleye, *Stizostedion vitreum vitreum*, (25 cm and greater) in West Blue Lake, Man., in May 1969 decreased from 1090 to 819 in May 1970. During summer and fall, the initial population was supplemented by new recruits, age II+, reaching a maximum of 3451 in September 1969. The total population in May 1970 was 2037. Mean daily mortality for all ages was small for the year, 0.0045, but loss rate was greatest in fall and winter. Growth in length was greatest for age II+ followed by older fish. Growth in weight was similar for ages III–V and lowest for age II+. Mean biomass, approximately 800 kg, was similar in May 1969 and May 1970. Production, 340 kg, coincided with the growing season (June to October) and was greatest from June to September. Greatest contribution to walleye production and biomass was made by age II+ fish. During winter and spring, zero or negative production occurred.

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La population de dorés jaunes (*Stizostedion vitreum vitreum*) (de 25 cm de longueur et plus) du lac West Blue, Manitoba, a passé de 1090 en mai 1969 à 819 en mai 1970. En été et en automne, de nouvelles recrues d'âge II+ sont venues grossir la population initiale, qui atteignait un maximum de 3451 en septembre 1969. En mai 1970, la population totale comptait 2037 individus. La mortalité quotidienne moyenne de tous les âges a été faible, 0.0045, durant toute l'année, mais le taux de perte atteignait un sommet en automne et en hiver. La croissance en longueur a été la plus forte chez les poissons d'âge II+, plus faible chez les poissons plus âgés. La croissance pondérale a été la même chez les poissons d'âges III à V; elle a été la plus faible chez les poissons d'âge II+. La biomasse moyenne, d'environ 800 kg, était la même en mai 1970 qu'en mai 1969. La production de 340 kg, coïncidant avec la saison de croissance (juin à octobre), atteignait un sommet de juin à septembre. Les poissons d'âge II+ sont ceux qui ont contribué le plus à la production et à la biomasse des dorés jaunes. La production a été nulle ou négative en hiver et au printemps.

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THE purpose of this paper is to describe seasonal biomass changes and production in the unexploited walleye (*Stizostedion vitreum vitreum*) population of West Blue Lake, Man.

Effects of angling and commercial fisheries on walleye populations have frequently been evaluated (Pycha 1961; Smith and Pycha 1961; Ryder 1968; Rose 1947; Forney 1967) but mortality and biomass changes have seldom been described for unexploited fish populations. Exceptions are the work of Ricker (1947) and Kennedy (1954).

Within-year changes in survival and biomass have seldom been evaluated. Ricker and Foerster (1948) and Alexander and Shetter (1961) have indicated seasonal decreases in unrecruited salmonid stocks. Ricker and Foerster (1948) determined mortality rates estimated for short periods of the year and used these rates, applied to an initial biomass estimate, to calculate biomass changes and production. We calculated a series of biomass estimates and used growth, recruitment, and survival data to estimate seasonal production. Basic data were provided by a series of mark-and-release experiments carried out

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during the period from May 1969 to May 1970. During this time, angling and commercial fishing were prohibited.

Methods and Materials

SAMPLING AND MORTALITY TRIALS

Fish were captured in a standard gang of three sections, each 30.5 m long and 1.8 m deep. Mesh sizes were 3.8, 6.4, and 8.9 cm, stretched measure.

The standard gang was set at one of the possible sites approximately ½ hr before sunset in 3–15 m of water. Previously, we failed to capture fish during daylight and at depths greater than 15 m. The net was continuously patrolled by boat and captured fish were transferred to a perforated "live box" divided into four equal compartments. Fishing sites were alternated so that all three basins received comparable fishing effort. Captured fish (to a maximum of 40), sorted according to the mesh size of the capturing net, were retained overnight in the live box (length 2.55 × 1.22 × 0.38 m deep), anchored approximatly 30 m offshore.

The following morning, total length and fork length were obtained for each active fish. Scales were taken from the left side just above the lateral line on a diagonal between the posterior insertion of the second dorsal and the anterior insertion of the anal fin. Fish were released after marking with a numbered streamer tag inserted between the interspinous rays of the spiny dorsal fin (Dell 1968).

To estimate mortality from handling and marking, eight or 12 fish, paired by length, were held in 560-liter fiber glass tanks (4–6 fish per tank) located on shore. One from each pair was subjected to procedures identical to those applied to marked-and-released fish. The other was transferred to the holding tanks with minimum handling. Water, supplied by pumps with intakes installed 1.5 m below the surface of the lake, was replaced in each tank at about 45-min intervals. Holding periods were: June 24–July 21, July 19–27, September 7–14, 1969, and May 20–28, 1970. No food was supplied during holding.

POPULATION ANALYSES

Six mark-and-recapture experiments were carried out during the year (Table 1). Recaptured individuals were classified according to their previous history.

Population abundance estimates from these data were calculated by the Petersen technique (Ricker 1958). New recruits, appearing in the population in September 1969 (Table 1), were readily recognizable by their size and were released as a separate lot. The population considered was age II^+ fish and older (total length generally greater than 25 cm).

The population was stratified by age by determining proportions of each age-group in the catch and by apportioning the estimate of total number (N) accordingly. Marked-and-recaptured fish in each age were too few to permit separate estimates.

Survival rates were estimated by an adaptation of Ricker's (1958) equation 5.2. Recaptures were at a point in time rather than over an extended period. Because sample sizes were small, survival — and consequently mortality — applied to the whole population. Fishing was prohibited, therefore all mortality resulted from natural causes.

An indirect method based on scale analyses was used to estimate growth rates. Several scales from one fish were mounted on an acetate slide and impressions made which were then examined at 43.5×. For each fish, the anterior scale radius from the focus and the distance of each annulus from the focus were recorded. Each slide was examined twice. Disagreement resulted in further reading.

TABLE 1. Numbers of walleye captured, released, marked, and recaptured in West Blue Lake during 1969 and 1970.

Marking period	No. captured and released	No. marked	Recaptures from marking experiment: 1	2	3	4	5
		1969					
May 14–20	111	111	–	–	–	–	–
June 16–22	107	97	10	–	–	–	–
Sept. 3–12	95 (III^+)[a]	81	8	6	–	–	–
	133 (II^+)[b]	119					
Oct. 5–12	86	79	2	3	2	–	–
		1970					
May 18–26	117	83	3	4	4	3	–
June 15–19	97	–	2	1	3	2	3
Totals	651[a]	489	25	14	9	5	3

[a] Excludes recruitment.

[b] Includes recruited individuals released as a cohort.

Fork lengths for a particular scale radius were variable, but variances were homogeneous ($\chi^2 = 37.16$ ns, df = 33). The linear regression was $Y = 85.86 + 1.61X$, where Y is fork length and X is scale radius in millimeters. Coefficient of determination ($r^2 = 0.99$) indicated that 99% of the variability in fork length could be attributed to changes in scale radius.

Annulus formation in most West Blue Lake walleye occurs during the last week in June (Glenn MS 1969); therefore, the growth year was the period from the end of June 1969 to the end of June 1970. Length increments were determined as follows: (1) An estimated scale radius from focus to the scale periphery was determined for each fish by using its fork length in the scale radius–fork length linear equation; (2) This theoretical distance was then compared to the actual measured distance to provide a correction term for all measurements for that particular individual (Hile 1941); (3) The distance ΔL was determined by subtracting the distance from the focus to the periphery from the distance from the focus to the outside annulus; (4) The distance between each annulus was determined using the above procedure; (5) Weight at time of capture and last annulus was found using the equation $\log W = -5.463 + 3.163 \log L$, where W = weight in grams and L = total length (Glenn MS 1969); (6) The difference, ΔG, was obtained by subtraction.

Average biomass ($\bar{B}$) of the stock, defined as all members age II$^+$ and older, was determined using the arithmetic mean of two adjacent biomass estimates (Chapman 1968). This method requires that time intervals between the biomass estimates be short. Production was calculated using $P = g\bar{B}$ where g is instantaneous growth in weight.

Results

Periods of marking, and consequent recapture, were of relatively short duration, and varied from 4 to 12 days in length (Table 1). No fish was recaptured twice.

The only mortality during holding trials occurred during the July 19–27 experiment; one unmarked and two marked fish died, all from different pairs. This holding trial was not held concurrently with a marking and release experiment (Table 1); therefore, we conclude that handling and marking did not produce immediate mortalities among the marked fish used to estimate abundance. This absence of mortality was supported by the lack of carcasses observed during routine shoreline patrols.

Assuming random distribution, the probability of recapture would be independent of the basin of release. Utilizing all three basins of release and recapture, the null hypothesis was accepted ($\chi^2 = 1.68$ ns, df = 4, $P < .05$). Although numbers of recaptures are low, they satisfy the minimum theoretical (expected) frequency of two for adequate chi-square approximation.

The data indicated considerable movement of walleye between basins. No evidence existed to indicate discrete subpopulations in West Blue Lake.

Rates of recapture of walleye aged II–IV were constant between adjacent mark and release periods as well as for the whole experimental period. Results of a 2 × 5 chi-square analysis applied to those recaptured and to those not recaptured indicated that no significant difference existed (χ^2 between 1.27 and 5.09 for 79–386 df) either between adjacent periods or throughout the entire experiment.

A total of 390 walleye, age II–VIII years, were identified according to the mesh size used to capture them (Fig. 1). Few age III$^+$ fish, generally the most vulnerable to the 6.4-cm section, were captured. Consequently, the length frequency of fish captured by this mesh could not be adequately defined. Both the 3.8 and 8.9-cm gillnets captured a wide range of sizes but had relatively narrow ranges of lengths in which capture was most efficient, 230–280 and 400–480 mm, respectively. The 6.4-cm net captured a broad range in sizes and no size seemed particularly vulnerable. A large degree of overlap existed among the three sections of the standard net.

Separation of new recruits from the initial stock was possible from information provided by length frequency distributions, which were determined for all catches and were similar in form. Recruits were a distinct group of small fish on the right of all length

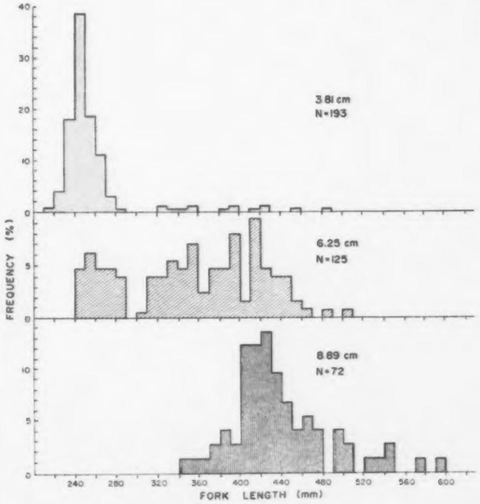


FIG. 1. Length–frequency distributions of walleye captured by 3.81-, 6.35-, and 8.89-cm gillnets in West Blue Lake, 1969 and 1970 (N represents number captured).

frequency curves. Age II$^+$ fish, nearing age III, also formed a distinct group in terms of length (Fig. 2), but no older groups were identified.

Original abundance, indicated by the May 1969 estimate (Table 2), declined markedly by May 1970 (new recruits excluded). New individuals entering the catchable population in September (N_2) more than doubled the number originally estimated (N_1) in May 1969. The maximum number within the stipulated size range occurred in the fall. The unrecruited May 1969 population was not appreciably altered, but new recruits greatly augmented the initial population. The population including recruits (N_2) suffered overwinter losses and decreased to a level somewhat greater than that of the previous spring (Table 2).

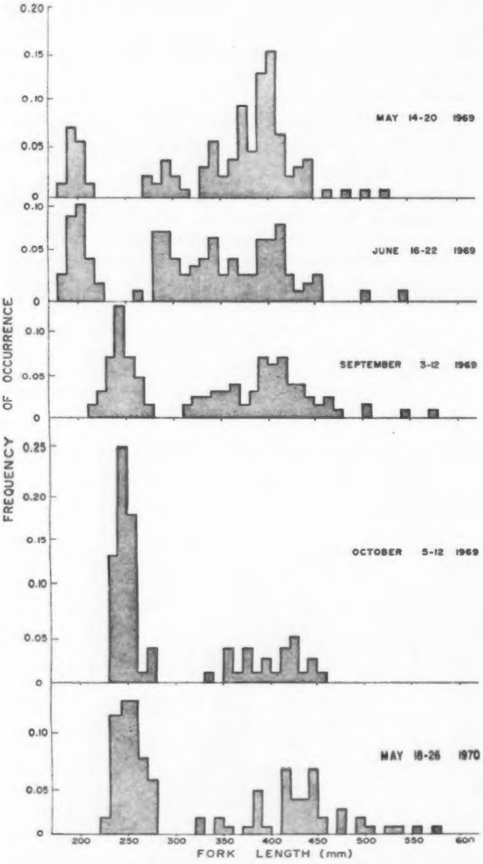


FIG. 2. Length–frequency distributions of walleye in West Blue Lake captured during mark-and-release experiments.

For abundance estimates, bias is approximated by the equation 100_e MC/N. Bias becomes negligible when the product of the two sample sizes ($M \times C$) exceeds the abundance estimate, N, by a factor of 3 or more (Robson and Regier 1964). In only one case, the May 1970 data, was the ratio of MC/N small enough (1.97) to introduce a significant bias into the estimate of N_1; therefore average estimates can be considered as 0.95 N, demonstrating negligible bias.

Instantaneous daily mortality rates (Table 3), calculated using tag recapture data from adjacent experiments, indicated that mortality was generally low throughout the year, but was greatest between September and October. Mean instantaneous daily mortality was 0.0045 and for the whole year was 1.6225.

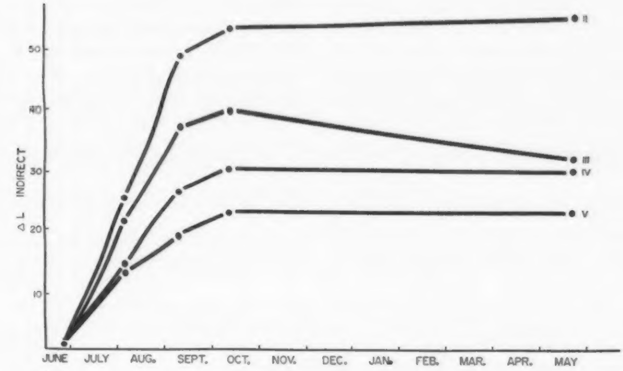
Growth, in terms of length increments, was greatest among age II$^+$ fish followed by fish aged III, IV, and V (Fig. 3). Since individuals older than five years were rare, analysis of growth data was limited to fish

TABLE 2. Estimates of West Blue Lake walleye abundance excluding (N_1) and including recruitment (N_2). Standard deviations are in parentheses.

Period	N_1	N_2
	1969	
May 14–20	1090(298)	1090(298)
June 16–22	1330(450)	1330(450)
Sept. 3–12	1350(654)	3451(1690)
Oct. 5–12	931(526)	2331(836)
	1970	
May 18–26	819(461)	2037(890)

TABLE 3. Survival and instantaneous mortality rates of walleye in West Blue Lake. Standard deviations are in parentheses.

Period	Survival rate (s)	Instantaneous mortality (i) per day
	1969	
May 14–20	$s_{12} = 0.999(\pm 0.465)$	$i_{12} = 0.00003$
June 16–22	$s_{23} = 0.835(\pm 0.546)$	$i_{23} = 0.0022$
Sept. 3–12	$s_{34} = 0.664(\pm 0.421)$	$i_{34} = 0.0136$
Oct. 5–12	$s_{45} = 0.525(\pm 0.407)$	$i_{45} = 0.0028$
	1970	
May 18–22		mean $i = 0.0045$



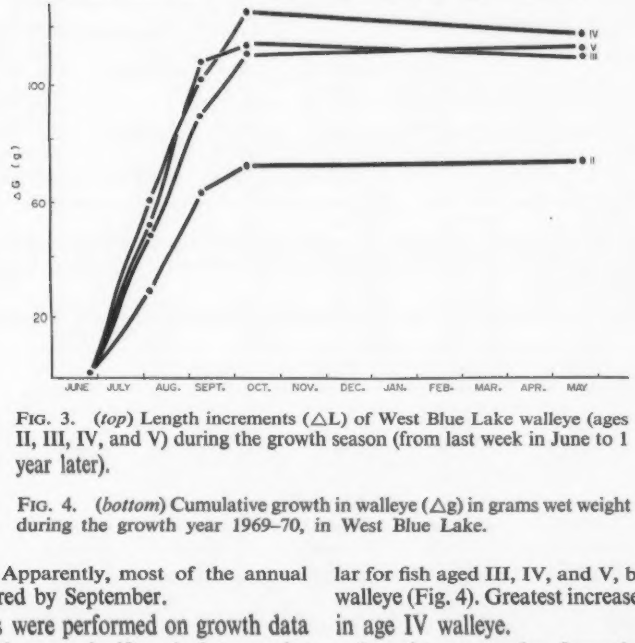


FIG. 3. (*top*) Length increments (△L) of West Blue Lake walleye (ages II, III, IV, and V) during the growth season (from last week in June to 1 year later).

FIG. 4. (*bottom*) Cumulative growth in walleye (△g) in grams wet weight during the growth year 1969–70, in West Blue Lake.

from age II⁺–V⁺. Apparently, most of the annual growth had occurred by September.

Paired "*t*" tests were performed on growth data to determine if fish grew significantly between ice break-up in May and annulus formation in late June 1969. Generally, no differences were found between fork length (except for age IV⁺ individuals) in samples of walleye collected from May 14 to 20 and from June 16 to 22, 1969. A significant difference occurred between mean lengths of age IV⁺ walleye collected in May and in June, ($F - 2.26$, $P = 0.05$, df = 89) but when growth from the last annulus was compared for the two collections, no difference was found ($F = 0.42$ ns, df = 87).

Length increments were greatest among age II fish with respectively smaller values for age III, IV, and V fish. Weight increments were approximately similar for fish aged III, IV, and V, but lowest for age II walleye (Fig. 4). Greatest increase in weight occurred in age IV walleye.

Lengths at annulus formation, estimated from scale data, indicated that, regardless of time of capture, previous growth history was similar (Table 4). The fork length estimated for annulus I (slightly out of the range considered by the length–scale radius equation) varied only slightly for each brood year, but the difference between brood years was rather large, from 136.5 to 163.8 mm. Brood year length differences persisted in older age-groups.

Instantaneous rates of growth between May and June 1969 were negligible (Table 5), confirming the results of the paired "*t*" tests. Magnitude of growth in relative and instantaneous terms was greatest between annulus formation and August. Growth was still rapid from August until September. Rates decreased until the period of October 5–12 and approached zero during winter. Relative and instantaneous growth was generally greatest in young fish but decreased with age. Although results indicated that some spring growth occurred, most growth (70–90%) was completed by September and virtually all growth (80–100%) was accomplished by October.

Population estimates ($\hat{N}_1$ and $\hat{N}_2$) were apportioned according to the relative abundance of age-

TABLE 4. Lengths of walleye at annulus formation in West Blue Lake, 1969–70 (N refers to number in each sample).

Brood year	N	AGE I	II	III	IV	V	Collection date
1967	48	140.9					May–June 1969
	150	136.5	194.2				Aug. 1969–May 1970
	37	137.8	199.9	259.9			Oct. 1970
1966	44	156.0	243.5				May–June 1969
	32	155.8	242.7	297.5			Aug. 1969–May 1970
	7	163.8	249.1	303.3	344.3		Oct. 1970
1965	40	154.8	237.9	311.3			May–June 1969
	20	153.6	240.6	313.3	351.4		Aug. 1969–May 1970
	4	158.3	239.6	314.6	362.5	399.3	Oct. 1970
1964	89	150.4	240.8	314.8	378.8		May–June 1969
	60	149.6	240.9	314.4	367.3	398.4	Aug. 1969–May 1970

TABLE 5. Relative growth in length and weight (H_L and H_G, respectively) from previous annuli and instantaneous daily rates of growth in length and weight (g_L and g_G, respectively) for walleye, 1969–70.

	May 14–20 1969	June 16–22	Aug. 2–4	Sept. 3–12	Oct. 5–12	May 18–26 1970
H_L	0.4092	0.3825	0.1222	0.2354	0.2638	0.2715
H_G	1.7453	1.7118	0.3855	0.8832	0.9957	1.0179
			Age I–II			
g_L	–0.00065	0.00335	0.00131	0.00197	0.00020	
g_G	–0.00039	0.00959	0.00943	0.00206	0.00005	
H_L	0.2046	0.2014	0.0693	0.1189	0.1260	0.1044
H_G	0.7623	0.7266	0.1884	0.3910	0.4072	0.4014
			Age II–III			
g_L	–0.00025	0.00199	0.00127	0.00029	–0.00096	
g_G	–0.00052	0.00838	0.00123	0.00047	–0.00031	
H_L	0.1182	0.1062	0.0392	0.0718	0.0832	0.0817
H_G	0.3616	0.3281	0.1280	0.2182	0.2633	0.2615
			Age III–IV			
g_L	–0.00027	0.00115	0.00079	0.00031	0.00000	
g_G	–0.00069	0.00359	0.00214	0.00107	0.00000	
H_L	0.0734	0.0719	0.0331	0.0444	0.0531	0.0536
H_G	0.2124	0.2119	0.0688	0.1263	0.1599	0.1604
			Age IV–V			
g_L	0.00004	0.00096	0.00032	0.00028	0.00000	
g_G	0.00001	0.00022	0.00122	0.00098	0.00000	

groups in samples. Age-group IV in May and June, becoming age V in late June, formed the largest portion of the population biomass. Biomass and production estimates for the first age-group were obtained by applying mortality rates calculated for the population (Table 6) to the estimated number of new recruits (2101 individuals) in September. This age-group contributed approximately half of the total production (167 kg) as a result of its abundance and high rate of growth ($g = 0.6313$).

There was a general seasonal decrease in age-group abundance (Table 6). Age-group V in September was the only obvious discrepancy, but because of slow growth they contributed little to production (12 kg). Variable production by age III^+ and VI^+ was caused by their scarcity in the population.

Biomass estimates (excluding estimated age I abundance) were similar in May and June 1969 (703 and 725 kg, respectively). Production between these periods was negative (losses occurred in ages I, II, and III).

Production of walleye flesh occurs from September to October (36 kg) and is essentially zero during the winter months (Table 6). Production in terms of net

TABLE 6. Estimates of biomass (B), mean biomass ($\bar{B}$) and production (P) (*kg*) for West Blue Lake walleye (the average weight (*g*) for individuals in each age-group is W and g_G is the instantaneous growth rate in weight[a]).

	Total for age-groups		Abundance	W	g_G	B		$\bar{B}$	P
May 14–20									
1969	1090	I	*2566*[c]	79.8	–0.0128	*204.767*			
		II	136	267.6	–0.0172	36.394			
		III	175	470.1	–0.0223	82.268			
		IV	573	676.7	0.0002	387.749	I	*205.031*	–2.6244
		V	167	861.5	0.0004	143.871	II	76.068	–1.3084
		VI	39	1354.4		52.822	III	108.223	–2.4132
						907.871	IV	360.233	0.0756
June 16–22	1330	I	*2563*	*80.1*	0.6313	205.296	V	107.343	0.0043
		II	410	282.3	0.3293	115.743	VI	62.356	0.0025
		III	302	444.3	0.1989	134.179		919.254	
		IV	467	712.4	0.1187	332.691			
		V	82	863.6	–	70.815	I	264.135	166.7484
		VI	69	1041.9	–	71.891	II	119.111	39.2233
						930.615	III	*123.165*	24.4975
Sept. 3–12	1350	II	2101	154.2	0.0619	323.974	IV	414.626	49.2161
	(3451)[b]	III	298	411.0	0.0143	122.478	V	159.406	18.9215
		IV	193	581.1	0.0322	112.153	VI	71.891	8.5335
		V	632	785.7	0.0295	496.562		1152.334	
		VI	227	1092.5	–	247.998	II	259.607	16.0970
						1303.164	III	125.413	1.7934
							IV	*129.773*	4.1774
Oct. 5–12	931	II	1200	162.7	0.0010	195.240	V	408.988	12.0652
	(2331)	III	298	430.7	0.0093	128.349	VI	*145.015*	4.2779
		IV	223	660.6	0	147.314		1068.796	
		V	373	861.7	0	321.414			
		VI	37	1136.0	0	42.032	II	188.904	0.1870
						834.349	III	90.732	0.8429
May 18–22							IV	108.355	0
1970	819	II	1118	163.3	–	182.569	V	388.931	0
	(2037)	III	150	354.1	–	53.115	VI	44.350	0
		IV	111	625.2	–	69.397		821.272	P=340.3175
		V	521	876.1	–	456.448			
		VI	37	1261.3	–	46.668			
						808.197			

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[a] Instantaneous growth rates are daily rates (Table 5) multiplied by days between the midpoints of adjacent sampling periods.

[b] Estimates in parentheses include recruitment.

[c] Italicized estimates were calculated from survival rates applied to September data (see text).

walleye weight was 340 kg during the 1969–70 growth year. Negative or zero production occurred from May to June and from October to May. Proliferation of flesh was limited to the period from late June to early October.

Discussion

Accuracy of biomass and production estimates depends on the precision of population, mortality, and growth estimates. Moyle (1950) and Berst (1961) have indicated that gear selectivity produced unrepresentative samples, but Forney (1961) demonstrated that the age structure in samples from gillnet catches was similar to the "real" population as indicated from trap catch data. Our catch data (Fig. 1) showed that total catches, made using the three mesh sizes, samples all fish longer than approximately 25 cm but each mesh size was selective. For instance, the 3.8-cm net sampled small fish more efficiently than either the 6.4- or 8.9-cm nets.

Catches made during the season (Fig. 2) provided some information regarding gear selectivity. The distinct group of small fish on the left of the size frequency distributions increased in average length during the year. The ability of catch data to demonstrate the change in mean length of this group indicated that, at least in this general size range, segments of the population were not unavailable.

Recaptured walleye, although too few for accurate estimates of growth, had grown at the rate calculated (Table 5) from seasonal gillnet catches. Although firm conclusions cannot be made, there is no evidence that gear selectivity was a major source of error. Similarly, the absence of mortality among fish held concurrently with the marking experiments indicated that an immediate differential mortality affecting only marked fish was not a source of error.

Small samples were probably not a serious source of error to population estimates because the estimates were generally demonstrated to be unbiased according to the criterion described by Robson and Regier (1964). Small samples did, however, contribute to wide limits in population abundance estimates (Table 3). Chapman (1968) indicated that the principal deficiency of any production estimate, namely large sampling error, can still inspire confidence when adequate precautions are taken and when production estimates are confined only to intervals between population estimates.

Because of the variety of errors affecting all parameters used to calculate biomass changes and production and because of possible interrelations, some errors may tend to cancel whereas others may be additive — actual biomass estimates and production may be considerably in error. Nevertheless, it is unlikely that the seasonal changes to be described were not real.

Both Ricker and Foerster (1948) and Alexander and Shetter (1961) described decreases in an unrecruited population similar to the decreases found in West Blue Lake walleye, but our results show that new recruits, age II$^+$ from spawning in 1967, significantly increased the May 1969 population (Table 2). Their maximum contribution, between 2100 and 2300, was made in September 1969. Considering recruits, the walleye population increased from approximately 1100 in May 1969 to over 3400 in September. During the winter it decreased again to 2037, but the May 1970 population was considerably more abundant than the one present during the previous May. This seasonal cycle in the abundance of fish over 25 cm results from seasonal changes in both growth, as it affects recruitment, and mortality.

Daily mortality rates, applying to the population as a whole, were low. Natural mortality in the West Blue Lake walleye population was generally low and also relatively constant. On the other hand, conversion of the total annual mortality rate to total survival (all age-groups) indicated that from 20 to 37% of the initial population survived to the following May. This represented a large natural loss from the population, far exceeding losses described by Regier et al (MS 1969) for Lake Erie and Forney (1967) for Oneida Lake. Results, however, agree approximately with those presented by Kennedy (1954) for lake trout in Great Slave Lake and for several other unexploited species (Ricker 1947).

Causes for mortality in West Blue Lake are not apparent, but in comparison with other populations (Forney 1961; Carlander 1945) these walleye seem short lived, very few surviving beyond six years of age. No major predators are abundant. Pike, *Esox lucius*, are present but rare.

Glenn (MS 1969) showed that West Blue Lake walleye in 1967–68 gained most of their annual growth in both length and weight during a relatively brief period, between late June and early fall. Similar results were obtained in terms of fork length in this study. Growth increments in weight followed a pattern similar to the pattern described for West Blue Lake walleye by Glenn (MS 1969). Again, most growth in weight was put on during a relatively brief period in summer.

Some growth may occur in walleye in the spring prior to annulus formation. Accepting the apparent maximum amount of spring growth, the data still indicated that the major fraction occurred in summer. Forney (1966) also found that most growth (90%) in walleye fry and fingerlings occurred prior to September. Hile (1941), too, found little or no growth in walleye in the May–June period. Furthermore, he concluded that weight loss occurred in winter.

Biomass and production data indicated that production was limited to the period between June and October 1969. During the remainder of the year net production was zero or negative. In general, production was maximal when growth was also high. In contrast, biomass changes reflect the seasonal interplay of growth mortality and recruitment.

Our results agree with the findings of Gerking (1962) who concluded that production in Wyland Lake bluegill sunfish occurred only in summer. He also found that production was greatest in the youngest vulnerable year-class, as we did.

The walleye population of West Blue Lake seems rather atypical because of the virtual absence of older fish, an unexpected situation in an unexploited population. This may mean that maximal production takes place in age-groups younger than in other lakes where older fish are relatively more abundant. It may also mean that the ratio of mean annual biomass to production (0.34) is somewhat higher in West Blue Lake than in populations with relatively more old fish, although this is speculative because similar data are lacking for other walleye stocks.

Annual production of walleye flesh in West Blue Lake in 1969–70 was 2.1 kg/ha compared with a mean catch of 2.8 kg/ha (2.5 lb/acre) for the Red Lakes stock in Minnesota during the period 1930–53 (Smith and Krefting 1954). Assuming that the Red Lakes were intensively fished and, therefore, catch approximated production, production in these two very different systems was similar.

Obviously the West Blue Lake population would be most efficiently exploited in late summer and early fall, during the period of rapid production. Conversely, a late spring and early summer fishery might remove fish before they had contributed significantly to new biomass. Other populations in north central North America may have similar production patterns.

We have presented evidence indicating year-to-year differences in abundance. The population of fish over 25 cm in May 1969 was about 1100, but in May 1970 the total was over 2000; seasonal variations were even more pronounced, increasing from 1100 to over 3400 and decreasing again to 2000 within a 12 month period. Biomass changes, although not independent of abundance changes, did not follow a similar pattern. Spring population estimates were different but biomass was similar. Evidently, in this unexploited population, natural regulation of numbers and biomass also occurs within a year and seems to follow a seasonal pattern.

Acknowledgments

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ALEXANDER, G. R., AND D. S. SHETTER. 1961. Seasonal mortality and growth of hatchery reared brook and rainbow trout in Michigan. Mich. Acad. Sci. 46: 317–328.

BERST, A. H. 1961. Selectivity and efficiency of experimental gill nets in South Bay and Georgian Bay of Lake Huron. Trans. Amer. Fish. Soc. 90: 413–418.

CARLANDER, K. D. 1945. Age, growth, sexual maturity, and population fluctuations of the yellow pikeperch, *Stizostedion vitreum vitreum* (Mitchill), with reference to the commercial fisheries, Lake of the Woods, Minnesota. Trans. Amer. Fish. Soc. 73: 90–107.

CHAPMAN, D. W. 1968. Production. *In* S. D. Gerking [ed.] Methods for assessment of fish production in fresh waters. Int. Biol. Programme Handb. 3: 313 p.

DELL, M. B. 1968. A new fish tag and rapid cartridge fed applicator. Trans. Amer. Fish. Soc. 97: 57–59.

FORNEY, J. L. 1961. Year-class distribution of walleyes collected by five types of gear. Trans. Amer. Fish. Soc. 90: 308–311.

1966. Factors affecting first year growth of walleyes in Oneida Lake, New York. N.Y. Fish Game J. 13: 146–167.

1967. Estimates of biomass and mortality rates in a walleye population. N.Y. Fish Game. J. 14: 176–192.

GERKING, S. D. 1962. Production and food utilization in population of bluegill sunfish. Ecol. Monogr. 32: 31–78.

GLENN, C. L. MS 1969. Seasonal rates of growth within a population of walleye, *Stizostedion vitreum vitreum* (Mitchill), in West Blue Lake, Manitoba, during 1966–1967. M. Sc. Thesis. Univ. Manitoba, Winnipeg, Man. 63 p.

HILE, R. 1941. Age and growth of the rock bass, *Ambloplites rupestris* (Rafinesque), in Nebish Lake, Wisconsin. Trans. Wis. Acad. Sci. Arts Lett. 33: 189–337.

KENNEDY, W. A. 1954. Growth, maturity, and mortality in the relatively unexploited lake trout of Great Slave Lake. J. Fish. Res. Bd. Canada 11: 827–852.

MOYLE, J. B. 1950. Gill nets for sampling fish populations in Minnesota waters. Trans. Amer. Fish. Soc. 79: 195–204.

PYCHA, R. L. 1961. Recent changes in the walleye fishery of northern Green Bay and history of the 1943 year class. Trans. Amer. Fish. Soc. 90: 475–488.

REGIER, H. A., V. C. APPLEGATE, AND R. A. RYDER. MS 1969. The ecology and management of the walleye in western Lake Erie. Great Lakes Fish. Comm. Tech. Rep. 15: 101 p.

RICKER, W. E. 1947. Mortality rates in some little-exploited populations of fresh-water fishes. Trans. Amer. Fish. Soc. 77: 114–128.

1958. Handbook of computations for biological statistics of fish populations. Fish. Res. Board Can. Bull. 199: 300 p.

RICKER, W. E., AND R. E. FOERSTER. 1948. Computation of fish production. Bull. Bingham Oceanogr. Collect. 11: 173–211.

ROBSON, D. S., AND H. A. REGIER. 1964. Sample size in Petersen mark-recapture experiments. Trans. Amer. Fish. Soc. 93: 215–226.

ROSE, E. T. 1947. The population of walleye in Spirit Lake, Iowa. Trans. Amer. Fish. Soc. 77: 32–41.

RYDER, R. A. 1968. Dynamics and exploitation of mature walleyes in the Nipigon Bay region of Lake Superior. J. Fish. Res. Bd. Canada 25: 1347–1376.

SMITH, L. L., AND L. W. KREFTING. 1954. Fluctuations in production and abundance of commercial species in the Red Lakes, Minnesota, with special reference to changes in the walleye population. Trans. Amer. Fish. Soc. 83: 131–160.

SMITH, L. L., JR., AND R. L. PYCHA. 1961. Factors related to commercial production of walleye in Red Lakes, Minnesota. Trans. Amer. Fish. Soc. 90: 190–217.

Stability of Elemental Phosphorus in Edible Muscle Tissue of Cod During Processing Including Icing, Freezing and Thawing, Frozen Storage, Salting, and Cooking

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Dyer, W. J., D. F. Hiltz, R. G. Ackman, J. Hingley, G. L. Fletcher, and R. F. Addison. 1972. Stability of elemental phosphorus in edible muscle tissue of cod during processing including icing, freezing and thawing, frozen storage, salting, and cooking. J. Fish. Res. Bd. Canada 29: 1053–1060.

Elemental phosphorus (P_{el}) in the white muscle of cod was remarkably stable during processing of the fish by commercial procedures. After iced storage (both as round fish and as fillets), freezing and thawing, frozen storage, or cooking, from about 40 to 100% of the original P_{el} concentration remained (except for a very few samples) during conditions approximating normal commercial handling. In pickle- and in kench-salted cod, 25% or more of the P_{el} remained after 1½–2 months.

At initial values of P_{el} up to about 500 ng/g, the rate of decrease during iced or frozen storage was very slow, but at higher initial values the rate was much more rapid. The lipid in which the P_{el} was probably dissolved may have protected the P_{el} up to the threshold concentration.

Commercial processing cannot be relied upon to make cod polluted with P_{el} safe for use as human food.

Dyer, W. J., D. F. Hiltz, R. G. Ackman, J. Hingley, G. L. Fletcher, and R. F. Addison. 1972. Stability of elemental phosphorus in edible muscle tissue of cod during processing including icing, freezing and thawing, frozen storage, salting and cooking. J. Fish. Res. Bd. Canada 29: 1053–1060.

Le phosphore élémentaire (P_{el}) du muscle blanc de la morue est remarquablement stable au cours des opérations de traitement commerciales. Après entreposage dans la glace (poisson entier aussi bien que filets), congélation, décongélation, entreposage frigorifique ou cuisson, dans des conditions se rapprochant de la manutention commerciale normale, de 40 à 100% environ de la teneur initiale du P_{el} est retenue. La morue saumurée ou salée à sec retient 25% de son P_{el} après une période de 1½ à 2 mois.

A des valeurs initiales de P_{el} allant jusqu'à environ 500 ng/g, le taux de diminution durant l'entreposage dans la glace ou sous refrigération est très lent. A des valeurs initiales plus élevées, le taux est beaucoup plus rapide. Il est possible que le lipide dans lequel le P_{el} est probablement en solution le protège jusqu'au point de concentration de seuil.

On ne peut donc compter sur le traitement commercial pour rendre la morue polluée par le P_{el} acceptable pour l'alimentation humaine.

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After an occurrence of pollution of a portion of Placentia Bay, Newfoundland, with elemental white (or yellow) phosphorus (P_{el}) (Idler 1969; Jangaard 1970), it was found in laboratory experiments that live Atlantic cod (*Gadus morhua*) exposed to sea water containing this pollutant rapidly accumulated it in the muscle, and especially in the liver tissue, in concentrations potentially toxic for food use (Dyer et al. 1970).

The results of monitoring marine organisms in Placentia Bay showed that absorption of P_{el} into tissue of various fish did occur in some instances and preliminary laboratory experiments with small salmon and smelt fillets indicated some degradation during frozen storage (Ackman et al. MS 1970). The stability of such absorbed P_{el} in the edible flesh

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during the handling, processing, and cooking conditions likely to be encountered during marketing and preparation of the product as food was, however, generally unknown.

Using cod which had been exposed in vivo to P_{el} in the sea water of a laboratory aquarium, we investigated the effects of icing both round fish and fillets, freezing and thawing, frozen storage, salting, and cooking procedures on P_{el} stability in the edible white flesh. In the experiments, the P_{el} showed remarkable stability; none of the processing methods yielded a product sufficiently free of P_{el} for safe use as human food.

Experimental

In the Placentia Bay area, cod is mainly caught by gillnet or in cod traps, with the fish being either salted for marketing as dried salt cod or filleted and frozen as cod blocks for use in a fish stick type of product; very little if any is sold as iced fillets (W. A. MacCallum personal communication). Cod is almost always landed ungutted and without ice, perhaps some 2–7 hr after boating. After gutting, usually at the wharf, the fish go to a holding room with some ice for 2–24 hr. They are then filleted, the fillets are well iced, often overnight, in 50–100 lb aluminum or plastic boxes, and trucked to freezing plants (some 45–75 miles distant). Estimated average time from catching to freezing is 2 days. For salting, the gutted fish are either kench salted (alternate layers of fish and salt with free drainage of pickle formed) or brine salted in tanks, the fish becoming immersed in the pickle formed. The salted fish remain in pickle or brine for 6 weeks or longer at summer temperatures prior to drying. It would be expected that both kench salting and drying would be conducive to oxidation of P_{el}.

The conditions of exposure to P_{el}, the initial concentrations of P_{el} in the cod used, and the analytical procedures for extracting and estimating P_{el} have been described previously (Dyer et al. 1970). The uniform distribution of P_{el} throughout the white muscle of the fillet (Dyer et al. 1970) greatly simplified the experimental designs since the same fish or fillets could be successively sampled throughout the various processing procedures. Sampling was usually done by excising several cores with a cork borer, either 1.1 or 1.5 cm in diameter, from the thicker parts of the fish or fillets, only white muscle being used in the present work. Extraction of P_{el} from cooked fish according to the procedure of Addison and Ackman (1970) proved troublesome at first because of the formation of a stiff gel which prevented separation of the isooctane layer. The following modification was satisfactory: to the sample was added three parts methanol and two parts isooctane, then the mixture was homogenized for 60 sec in a small metal cup cooled in ice. The mixture was filtered on a Buchner funnel and the isooctane layer separated.

The cooking methods used were boiling (in polyethylene bags suspended in boiling water) and baking (samples wrapped in aluminum foil). Any drip separating on cooking was returned to the samples in proportion to the amounts taken for analysis.

The various processes selected in the experiments were designed to approximate the average commercial handling conditions.

EXPERIMENT 1

Initial sampling — To examine P_{el} stability in cod iced both round and as fillets, and after freezing and thawing (both raw and after cooking), five cod were sampled 15–30 min after removal from the aquarium in which the fish had been held in sea water with a P_{el} suspension (fish M–Q as described by Dyer et al. 1970). The sequence of analyses was as follows:

Gutted fish sampling (24 hr postmortem) — The five fish were held round at + 15 C for 4 hr, gutted and held in ice for 20 hr, and then filleted and sampled.

Iced fillet sampling (48 hr postmortem) — The fillets were sampled after being held in ice for 24 hr.

Frozen and thawed sampling — The iced fillets were then packed two deep in a 6-cm thick carton, quickly frozen in a plate freezer, and stored at –18 C for 7 days. They were then thawed overnight in a room at + 2 C and resampled. No drip formation was apparent.

Cooking — The samples for cooking were heated in a polyethylene bag immersed 8 min in boiling water except that the frozen and thawed samples from fish N and P were baked (wrapped in aluminum foil and held for 8 min in an oven at 475 F) as a check for possible differences due to cooking procedure. The cooking times selected gave optimum doneness in parallel tests on untreated fish.

EXPERIMENT 2

As a further check on P_{el} stability in cod fillets at ice temperature, fillets from Fish X–Z were placed in polyethylene bags to prevent possible leaching of P_{el}, immersed in crushed ice, and sampled at 0, 2, 4, 7, and 11 days. Four cores were taken from the thick dorsal area of the fillet (areas 2-7 of Dyer et al. 1970) and combined into one sample for each fillet.

EXPERIMENT 3

A preliminary experiment was conducted to determine the stability of the P_{el} during cooking. The initial concentrations of P_{el} in single whole fillets (blended and extracted raw) of fish E–H were, respectively, 570, 560, 490, and 490 ng/g; those in the corresponding fillets cooked in a polyethylene bag immersed in boiling water for 25 min were 30, 640, 150–180–180, and 10–10–20 ng/g. Cook-drip was incorporated into the samples, and evaporative losses were about 2%, too small to affect the results appreciably. Thus the recovery in these cooked fillet samples varied widely between 2 and 100%, probably indicating poor extraction of the P_{el}, and the extraction method was modified for subsequent work as indicated earlier.

Experiments with fish I–L followed, but using smaller samples, duplicate cores of 10 g each from the thick dorsal section of both left and right fillets. One core was extracted raw, and the other, enclosed in a polyethylene bag, after cooking in a boiling water bath for 8 min.

Another lot of fillets from five cod (GG–KK) were baked whole, wrapped in aluminum foil, for 26 min in an oven at 260 C. For analysis, two samples consisting of two cores each were taken from the thick portion of each of the two fillets of each fish prior to and following cooking. Small portions of the cores for each fillet were taken for moisture determination — the results on the cooked samples being corrected for evaporative moisture loss.

EXPERIMENT 4

To check stability in salted fish, experiments were conducted by both the brine (saturated NaCl) and dry salt (kench) processes.

For the brined fish, fillets, skin on, of fish R–T were salted in a jar with Inagua Fishery salt (~ 30 parts per 100 parts fish) at approximately 20 C. A weight was placed over the fillets to keep them immersed in the pickle formed. At intervals during 44 days, four core samples were taken from the thick area of each fillet and combined into one sample per fillet for analysis. Half of each core (cut lengthwise) was used for P_{el} extraction, and the other half for moisture (weight loss in 24 hr at 105 C) and NaCl analysis. Salt was estimated in the dried residue by boiling with distilled water (breaking up lumps) and measuring the chloride concentration with a chloride ion electrode (Orion Research Inc., Cambridge, Mass.).

The P_{el} content found was corrected for loss of water and uptake of salt and expressed on the fresh weight basis. On the assumption that no P_{el} was lost in the water diffusing from the flesh during the salting process, the P_{el} concentration was calculated on the basis of salt-free solids present in the fresh and salted tissue. At 2 days the moisture averaged 60.1 (SE of mean 0.9)% and the salt 16.5 (± 0.7)% (six samples, as % by weight out of pickle). Between 4 and 44 days the composition remained constant, average values being 56.4 (± 0.1) % moisture and 19.3 (± 0.1) % salt for 24 samples.

For kench salting, six cod (AA–FF) were gutted and split and sampled for initial P_{el} concentration by taking four cores (combined) of the white muscle only from the thick part of each side of the fish. The fish were salted with about 30 parts Inagua Fishery salt per 100 parts fish and then left in kench on a wooden platform and loosely covered with a polyethylene film for 58 days in an unheated wet lab at about 15–20 C. They were then resampled and dried on wire mesh trays in a tunnel air-drier with a fan, using room air at 21 C, to an average weight loss of 26% (with overnight presspiling). At 64 days after salting, they were resampled and stored at laboratory temperature for about a week (loosely wrapped in polyethylene film). Pieces approximately 10 × 12 cm from the midsection were soaked in cold water overnight (two changes), cooked 25 min in boiling water, and resampled. Moisture and salt were also determined on all samples (cores halved lengthwise) as for the brine-salted fish, and the P_{el} concentrations were recalculated on the basis of original weight (Table 3).

EXPERIMENT 5

P_{el} stability during frozen storage was checked at three storage temperatures. The fillets from a lot of six fish (LL–QQ) were each cut into seven pieces corresponding to areas 2–7 and 9 of fig. 1 of Dyer et al. (1970), red muscle and skin being carefully trimmed off. Each piece was placed in a small bag of polyethylene film, wrapped in aluminum foil, and then quickly frozen in a plate freezer. The pieces from each fish were grouped into three lots for frozen storage at –10, –18, and –26 C. Prior to freezing and at various intervals pieces were removed and sampled by taking two cores per piece for P_{el} extraction. The frozen samples were allowed to thaw overnight in a 3 C room prior to analysis. Of the six fish, the initial sampling showed three fish to have had a high P_{el} uptake and three a moderate uptake (averaging 1310 and 510 ng/g, respectively).

Results

EFFECTS OF ICING COD, BOTH ROUND AND AS FILLETS, AND OF FREEZING AND THAWING

These treatments (experiment 1) did not appreciably reduce the concentration of P_{el} in the white muscle from the initial value of approximately 500 ng/g (Table 1). Analysis of variance (Snedecor 1956) and Duncan's range test (Miller and Freund 1965) showed no significant difference ($P = 0.05$) between the initial, 24 and 48-hr samplings of the iced fish, or between the initial sampling and the frozen and thawed fillet samplings.

Holding the round fish for 4 hr at 15 C, with further holding in ice for 20 hr after gutting, resulted in a higher but not statistically significant ($P > 0.05$) average value. Freezing and thawing, with frozen storage at −18 C for 7 days, however, resulted in a small decrease ($P = 0.05$) from the iced fillets. Variation in P_{el} concentration between fish or fillets within the various lots was similar to that reported in the initial sampling (Dyer et al. 1970).

The loss of P_{el} in another lot of iced fillets (fish X–Z) stored up to 11 days in ice (experiment 2) showed a decreasing linear trend in one fish (X) with a high initial P_{el} concentration, 1000 ng/g, the regression line ($P = 0.01$) being $Y_1 = 1002 - 57.8X_1$, where $Y_1 = P_{el}$ concentration and X_1 = days in ice, but no decrease was evident in the other two samples with low initial P_{el} values (Fig. 1).

EFFECT OF COOKING

The preliminary experiments (fish E–H and I–L) had indicated some loss of P_{el} in cooking. Because in the cooked whole fillets (boiled) the recovery varied between 2 and 100%, the analysis of variance did not show that cooking caused a significant reduction and hence the extraction method for P_{el} was modified.

With small samples (~ 10 g, fish I–L, Table 2) cooked for a short time (8 min), the decrease on

TABLE 1. Concentrations of P_{el} in cod exposed to the element in aquarium: after being iced both round and as fillets and after freezing and thawing — samples analyzed raw and after cooking (values expressed as ng/g, wet weight, white muscle; fish M–Q, experiment 1).

Sampling time	Raw[a]	Cooked[b]
Round-initial	488±41[c,d]	259±38[c]
Round-gutted		
24 hr postmortem	608±47[c]	445±43[d]
Iced fillets		
48 hr postmortem	611±42[c]	571±32[e]
Frozen and thawed	447±50[d]	415±48[d]

[a] Mean and standard error of mean; four samples from each of the five fish.

[b] Cooking did not significantly affect the P_{el} concentration (multiple range test, $P = 0.05$) except for the initial sampling (P — 0.001).

[c–e] The means with the same superscript within each group, raw or cooked, are not significantly different (multiple range test, $P = 0.05$).

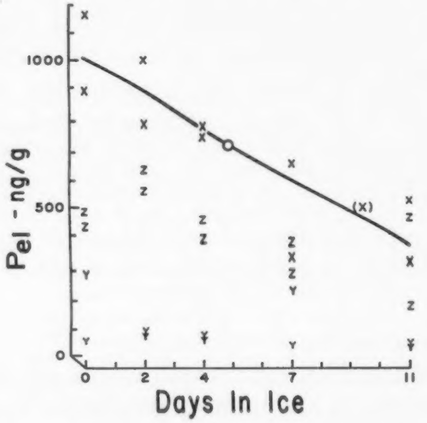

FIG. 1. P_{el} decrease in cod fillets during storage at ice temperature (fish X–Z, experiment 2). Calculation showed a significant ($P = .01$) linear regression for fish X, ($Y_1 = 1002 - 57.8 X_1$, where $Y_1 = P_{el}$ concentration and X_1 = days in ice) but no significant trend (linear, logarithmic, or inverse) for fish Y or Z.

TABLE 2. Effect of cooking on P_{el} stability (values as ng/g muscle in core samples, ~ 10 g, from right (r) and left (l) fillets of fish I–L, experiment 3).

	I		J		K		L		
Sample	r	l	r	l	r	l	r	l	Mean
Initial	600	580	590	700	590	600	480	440	572±29[a]
Cooked	350	450	180	350	170	460	240	360	320±40
% remaining	58	77	31	50	29	77	50	82	57± 7.3

[a] Standard error of mean.

cooking was highly significant ($P \sim 0.001$), but an average of 57% still remained after cooking. The variability of results was much greater for the cooked than for the raw samples, the standard errors of the mean expressed on a percentage basis being 12.5 and 5.1 %, respectively.

The results of cooking of sample cores of fish M–Q (Table 1) indicate no significant ($P > 0.05$) effect of cooking except for the initial sampling, where the unmodified extraction procedure was used. The salient point is that, although there may have been some heat destruction, or poor extraction of P_{el} in the initial sampling, there was no significant loss in the other stages, and even in the stage l samples less than 50% of the initial P_{el} content was labile upon cooking. Comparison of baking and boiling cooking techniques (both for 8 min on core samples of ~ 10 g) for the frozen and thawed samples showed no differences resulting from the cooking method and P_{el} values were unchanged from those for the raw samples. The eight samples baked in an oven at 260 C averaged 406±49, whereas those cooked by immersing the samples, enclosed in polyethylene bags, in boiling water averaged 421± 74 (12 samples). The initial concentration averaged 447 ng P_{el}/g.

When a longer baking time (26 min) was used, however, with fillets from fish GG–KK, a significant $P \sim 0.001$) reduction occurred in P_{el} concentration, but an average of 39% still remained after cooking. The P_{el} value for the raw samples averaged 940 ± 74 ng/g (20 analyses) as compared to an average of 363 ± 38 ng/g (20 analyses) for the cooked samples after correction for a small loss of moisture by evaporation (moisture content 78.5% versus 80.8% for the raw samples).

EFFECTS OF SALTING, DRYING, SOAKING, AND COOKING

Cod fillets salted in brine at approximately 20 C exhibited a rapid decrease in P_{el} concentration in the initial storage period, after which the rate of decrease was considerably slowed, approximating a hyperbolic relationship (Fig. 2). Fish R showed a more rapid decrease than the others, but even after 1½ months about 5% of the initial P_{el} content remained, compared to about 25% in fish S and T. At this time the rate of loss appeared to have become very slow.

Similar results were obtained from the lot of fish salted in kench, the P_{el} value after 58 days having been reduced to about 25% of the initial value (Table 3). Further processing by drying, and by soaking in water overnight, followed by cooking in boiling water for 25 min, resulted in only a minor further change. Lack of sampling between the initial and 58 day points precluded determination of the form of the loss curve.

EFFECT OF FROZEN STORAGE

Since freezing and thawing resulted in only a small decrease in values of P_{el} (Table 1), the effect of frozen storage at temperatures of -10, -18 and -26 C was investigated. Samples from the three fish (OO–QQ) with a moderate initial P_{el} concentration, averaging 507 ng/g, showed no significant ($P \sim .05$)

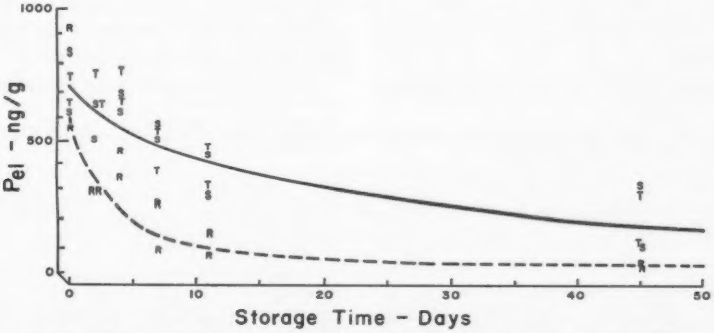

FIG. 2. Decrease of P_{el} in flesh of cod fillets during storage in NaCl brine (saturated) (experiment 4). The best fit to the data was given by hyperbolic equations (plotted in the figures) for fish R($\frac{1000}{Y}$ = 1.50 + 0.74 × ($P \sim$ .001)) and for fish S + T ($\frac{1000}{Y}$ = 1.39 + 0.96 × ($P \sim$ .001))
Data for fish S and T were combined since they did not differ in slope or level (X = days storage and Y = P_{el} concentration).

change on storage at any of the three temperatures up to at least 43 weeks (Table 4). In the samples with high initial P_{el} values there was a decrease ($P = 0.05$), however, at all three temperatures. The rate was practically the same at –18 and –26 C, the combined results showing significant differences from the initial at 14 weeks (decrease of 39%), and a further significant decrease between 14 and 43 weeks storage (Duncan's means test, $P = 0.05$), although 46% of the initial P_{el} remained (Fig. 3). At –10 C the initial rate of decrease of P_{el} concentration was much more rapid than at lower temperatures, but had almost reached an asymptotic level at between 5 and 14 weeks, with only a slow further decrease to 43 weeks. At this point, 32% of the initial P_{el} content was still present.

Discussion

The stability of P_{el} in the white flesh of cod processed in various ways is indeed remarkable. Iced storage, either round or as fillets, freezing and thawing, salting, frozen storage, and cooking all resulted in some decrease of the P_{el} originally present, but in almost all of the processed samples about 40% or more remained. Therefore, processing for use as food by any of the commercial methods presently in use in Newfoundland cannot be relied upon to provide a wholesome product from cod which might acquire potentially toxic levels of P_{el} should sea water again become contaminated with P_{el}. It had previously been observed (Dyer et al. 1970) that red muscle had an accumulation several times that of the white, thus contributing further to the toxicity potential of contaminated fish as food.

TABLE 3. Loss of P_{el} in kench-salted split codfish (fish AA–FF, experiment 4).

	P_{el} (ng/g)			
Sample	Found	Recalculated[a]	H_2O (%)	NaCl (%)
Initial	320(±38)[b]	–	81.0	–
Salted	90(±17)	73±14	55.6	21.1
Dried	51(±13)	21± 8	43.3	25.6
Soaked and cooked	81(± 9)	54± 6	66.5	4.7

[a] To original weight.

[b] Mean and standard error of mean for 12 samples.

It appears that during holding of the round or gutted fish the P_{el} accumulated in the white muscle in vivo prior to catching is not augmented to a significant extent by any diffusion or transfer from liver or other organs, or from the skin, since increases were not found when round or gutted fish were left at room temperature up to 4 hr, or at ice temperature for 20 hr. This, of course, might be expected if the P_{el} were mainly present in the fat or phospholipid fraction rather than being dissolved in aqueous tissue fluids (Dyer et al. 1970) in which diffusion would be more rapid.

The stability of P_{el} in iced fillets with initial concentrations of about 500 ng/g in comparison with the marked decrease for fillets with initial values of about 1000 ng/g (Fig. 1) and the similar finding for fillets in frozen storage (Table 4, Fig. 4) suggest that there is a threshold level at approximately 500 ng/g, at which point the remaining P_{el} is stabilized. Lower levels were, however, reached in salted cod, although here processing temperatures were much higher, 15 to 20 C, and reactions and diffusion might be expected to be more rapid. Losses of P_{el} to the brine would probably not occur because of the preferential solubility of P_{el} in the tissue lipid.

With cooked samples there was a notable tendency

TABLE 4. P_{el} values (ng/g) for cod muscle after frozen storage for 14 and 43 weeks at –10, –18, and –26 C of fish with high and with low initial concentrations (fish LL–QQ, experiment 5).[a]

		Weeks at –26 C		Weeks at –18 C		Weeks at 10 C			
Fish	Initial unfrozen	14	43	14	43	5	8	14	43
LL–NN	1308±69[b,d] (1154–1462)[c]	815±35 (718–912)	637±92 (382–891)	794±36 (694–894)	575±59 (411–738)	522±88[f] (278–765)	765±91[e] (512–1018)	539±73[e,f] (337–741)	420±41[f] (305–535)
OO–QQ	507±51 (392–621)	627±86 (386–867)	663±39 (553–772)	458±69 (266–650)	581±26 (507–654)	364±58 (202–526)	433±35 (336–530)	449±39 (341–556)	484±74 (277–690)

[a] In each group of three fish, one sample from each of the two fillets per fish was analyzed at each sampling time after frozen storage; at the initial sampling, two samples from each fillet were analyzed. Since there was no difference between the right and left fillets, only averaged results are shown. At –10 C, Duncan's range test, as indicated by superscripts d–f, shows decreases ($P = 0.01$) from the initial value for all storage periods, the value at 8 weeks being higher ($P = 0.05$) than those at 5 and 43 weeks.

[b] Standard error of mean.

[c] 95% confidence interval.

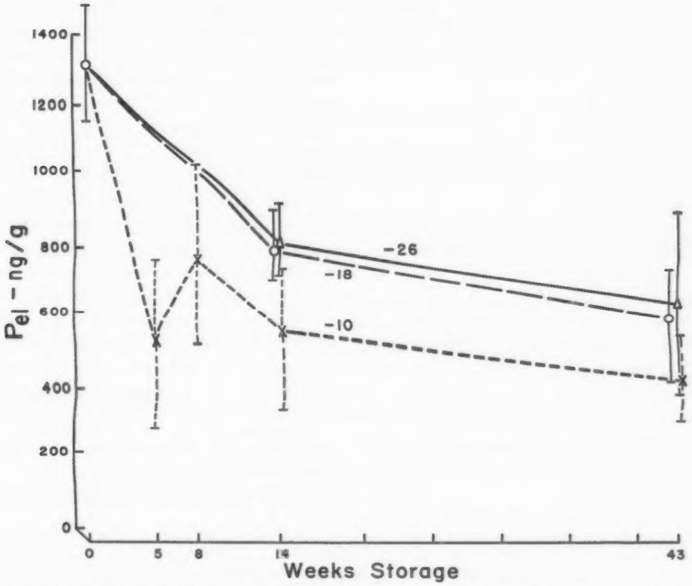

FIG. 3. P_{el} decrease in cod muscle during frozen storage at –10, –18, and –26 C for fish with high initial concentrations (fish LL–NN, experiment 5). 95% confidence intervals of the means are shown.

to variability of results. This could be due to a varying effect of heat or rate of cooking, but especially in the early experiments prior to use of the modified extraction procedure, it seems to be at least partially a result of incomplete extraction. This variability, however, does not affect adversely the interpretation of results since the P_{el} values found after cooking were usually sufficiently high to be considered in the toxicity range. Cooking time may be a factor influencing degree of loss of P_{el} by cooking, but the results are not conclusive; whole fillets cooked 25–26 min showed 61% loss (GG–KK) while 8 min cooking indicated no loss (M–Q) or 43% (I–L).

It is noteworthy that in the salted and in the frozen stored cod the concentration decrease was at first very rapid and then became asymptotic or nearly so (linear in iced fish, one case only). This contrasts with a first order decay reaction suggested by Zitko et al. (1970) for a water suspension of P_{el}. However, the P_{el} in the muscle is probably dissolved in the lipid (Ackman et al. MS 1970; Dyer et al. 1970) and consequently reaction rates probably depend more on oxygen diffusion into the lipid and would be slower and more complex than in water. The results indicate that about 500 ng/g of the P_{el} must be present in a very stable form, which does not react with tissue water or become oxidized. One might suggest that the lipid is capable of "protecting" only a certain concentration of P_{el}. If this is so, then the possible presence of higher threshold levels (expressed on the basis of wet tissue weight) in red muscle or in the flesh of more fatty species should be checked. Some results (though very variable) with frozen smelts (*Osmerus mordax*) stored at –40 C (Ackman et al. MS 1970) agree with the cod results, there being a rapid decrease in P_{el} values in the initial storage period when initial values were high, 500–3450 ng P_{el}/g, with levelling off at about 100–500 ng/g after about a week's storage (Fig. 4). Initial values were higher with very small frozen salmon (*Salmo salar*), 1000–5000 ng/g, and the decrease appeared almost linear to 3 months storage, with proportionally faster decrease the higher the initial value—the dependence on the initial concentration suggesting a first order reaction. Unfortunately, the examination was not carried far enough to demonstrate a stability level (there is some evidence of a plateau between 500 and 2000 ng/g). The lipid contents of the salmon used were not measured but were estimated at about 1% by the authors; the smelt contained about 2–3% fat. Possibly there may be a higher stability threshold in the salmon, while the smelt may be similar to the cod. The individual samples for salmon and smelt had been stored in small polyethylene bags, which allow fairly ready oxygen diffusion, whereas the frozen cod samples had been wrapped as well in aluminum foil, to restrict oxygen to that contained in the package. The rate of reaction in frozen storage seems to be considerably more rapid in the salmon and smelt at -40 C than in the cod at -26 C, the half-life of the initial P_{el} concentration being, respectively, about 12 weeks (two weeks for A_1), < 1 week (Fig. 4), and 30–40 weeks (Fig. 3). In cod there is very little triglyceride fat, and the phospholipid is mainly associated with membranes, while the triglyceride in other species is present mainly as fat globules in the tissue. It is suspected that in the frozen state the latter may be more accessible to oxidation by oxygen diffusion while any P_{el} associated with cod phospholipids might be protected by layers of protein.

Acknowledgments

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Ackman, R. G., R. F. Addison, and J. Hingley. MS 1970. An assessment of the assimilation of elemental phosphorus by Newfoundland marine organisms in the 1969 pollution problem and in 1970 monitoring operations. Fish. Res. Board Can. Tech. Rep. 208: 39 p.

Addison, R. F., and R. G. Ackman. 1970. Direct determination of elemental phosphorus by gas-liquid chromatography. J. Chromatogr. 47: 421–426.

Dyer, W. J., D. F. Hiltz, R. G. Ackman, J. Hingley, and G. L. Fletcher. 1970. In vivo assimilation by cod muscle and liver tissue of elemental phosphorus from polluted sea water. J. Fish. Res. Bd. Canada 27: 1131–1139.

Idler, D. R. 1969. Coexistence of a fishery and a major industry in Placentia Bay. Chem. Can. 21(11): 16–21.

Jangaard, P. M. 1970. The role played by the Fisheries Research Board of Canada in the "red" herring phosphorus pollution crisis in Placentia Bay, Newfoundland. Circ. 1, Office of the Atlantic Regional Director, Research, Halifax, N.S. 20 p.

Miller, I., and J. E. Freund. 1965. Probability and statistics for engineers. Prentice-Hall, Englewood Cliffs, N.J. 432 p.

Snedecor, G. W. 1956. Statistical methods. 5th ed. Iowa State University Press, Ames, Iowa. 534 p.

Zitko, V., D. E. Aiken, S. N. Tibbo, K. W. Besch, and J. M. Anderson. 1970. Toxicity of yellow phosphorus to herring (*Clupea harengus*), Atlantic salmon (*Salmo salar*), lobster (*Homarus americanus*), and beach flea (*Gammarus oceanicus*). J. Fish. Res. Bd. Canada 27: 21–29.

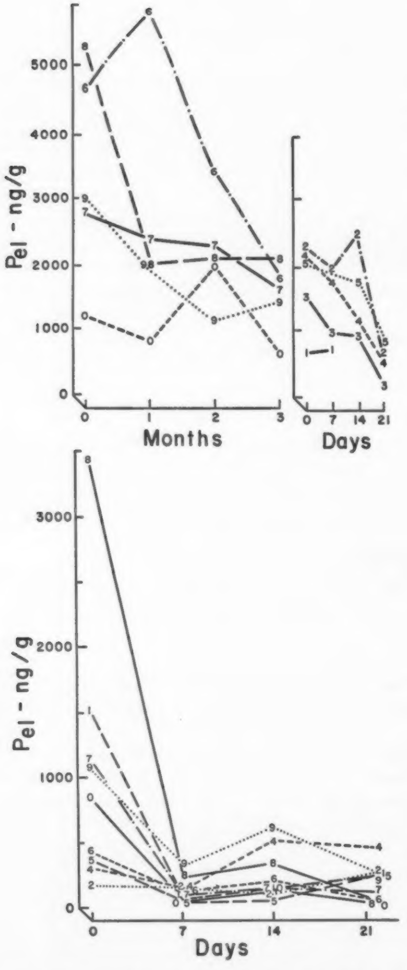

FIG. 4. Decrease of P_{el} in frozen salmon smolt and smelt fillets stored at -40 C. Data of Ackman et al. (1970). Five salmon smolt (18 cm long) from each of two lots exposed to a P_{el} dispersion in sea water (*upper panels*) were filleted and the fillets (skinless) cut transversely in four equal length sections from nape to tail labeled A to D, respectively. The samples from one fillet of each fish were analyzed immediately, the corresponding samples from the other fillet being stored individually in polyethylene bags at -40 C. Samples from lot A_1 were analyzed weekly, and those from lot A_2 monthly. Nine smelt averaging 14 cm in length (*lower panel*) were treated similarly except as follows: since initial values for section D, the tail section, were considerably lower than for the others they were omitted and the initial values (zero time in storage) are averages for the three sections. Values at each subsequent sampling are for single analyses for section A, B, or C only for each fish.

Evidence that Pacific Ocean Perch (*Sebastes alutus*) in Queen Charlotte Sound Form Aggregations that Have Different Biological Characteristics

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GUNDERSON, D. R. 1972. Evidence that Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound form aggregations that have different biological characteristics. J. Fish. Res. Bd. Canada 29: 1061–1070.

Pacific ocean perch (*Sebastes alutus*) in market samples from Queen Charlotte Sound showed considerable variation in mean length, even when narrowly defined month-depth strata were considered. Available evidence indicated that there was also considerable between-sample variability in growth. Both phenomena were attributed to a tendency for commercially exploited Pacific ocean perch to form distinct aggregations, each with different biological characteristics. The relevance of aggregating behavior to age and growth analyses is discussed.

GUNDERSON, D. R. 1972. Evidence that Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound form aggregations that have different biological characteristics. J. Fish. Res. Bd. Canada 29: 1061–1070.

Des échantillons de perches de mer du Pacifique (*Sebastes alutus*) provenant du détroit de la Reine-Charlotte, prélevés sur le marché, accusent des différences considérables de longueur moyenne, même lorsque les échantillons sont étroitement stratifiés quant au mois et à la profondeur de capture. De plus, le rythme de croissance varie beaucoup d'un échantillon à l'autre. Ces deux phénomènes sont attribuables à la tendance de la perche de mer du Pacifique exploitée commercialement à former des groupes distincts, ayant chacun ses propres caractéristiques biologiques. Nous examinons l'applicabilité de ce comportement aux analyses d'âges et de croissance.

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SINCE the time of R. Lee (1912) it has been suspected that certain commercial fish aggregate by size. Lebedev (1946) and Schaeffer (1948), working with anchovy (*Engraulis encrassicholus*) and tuna (*Neothunnus macropterus*), respectively, were the first to actually document the phenomenon. Roach (*Rutilus rutilus*), Kilka (*Clupeonella delicatula*), bream (*Abramis brama*), ocean perch (*Sebastes marinus*), cod, and herring are among other commercial species known to aggregate by size (Lebedev 1967).

Such aggregations could originate through hydrodynamic differences between individuals, since large fish can generally swim faster and sustain high speeds longer than their smaller counterparts (Bainbridge 1958). Lebedev (1967) found that in certain species behavior and physiology varied as much as length between aggregations. He concluded that differences between aggregations often entail more than size or hydrodynamics, and that each aggregation could be considered as a discrete unit or "elementary population."

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It is the purpose of this paper to present evidence showing that the commercially exploitable Pacific ocean perch (*Sebastes alutus*) stock in Queen Charlotte Sound is subdivided into aggregations of similar-sized fish, and that these aggregations differ in biological characteristics other than length.

Methods

Sampling techniques — All data were derived from 1966 through 1969 commercial catches made in Queen Charlotte Sound (Fig. 1). The technique used to sample these catches has previously been examined (Gunderson 1970) by comparing three samples from each of four catches made in a restricted area-depth-time stratum. No significant within-catch (between sample) differences in length were found, indicating that no bias is inherent in the sampling process itself.

An attempt was made to obtain length frequency (fork length) by sex for 200–500 fish in the catch. Otoliths were generally taken from subsamples of 100–200 fish.

Each otolith was read three times by three different readers or until two of the readers agreed on an age for it. When there was no agreement in three readings and the readings spanned only 3 years the median age assigned was accepted as the age for that otolith. Readings that

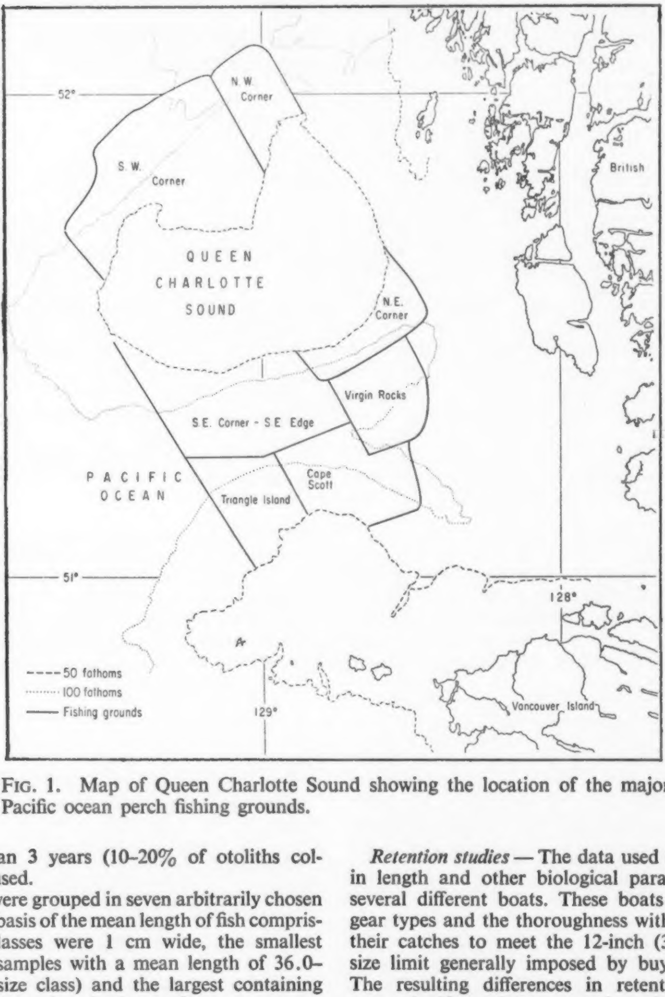

FIG. 1. Map of Queen Charlotte Sound showing the location of the major Pacific ocean perch fishing grounds.

spanned more than 3 years (10–20% of otoliths collected) were not used.

Catch samples were grouped in seven arbitrarily chosen size classes on the basis of the mean length of fish comprising them. Size classes were 1 cm wide, the smallest containing those samples with a mean length of 36.0–36.9 cm (36-cm size class) and the largest containing 42.0–42.9 cm (42-cm size class) samples.

The first objective was to examine variation in length within Queen Charlotte Sound. Westrheim (1970) has already shown that length composition of Pacific ocean perch frequently varies with depth, and to eliminate this effect length variation was considered over narrowly defined depth strata. All samples used to do this came from catches made over a depth range of 30 fath or less, and most (80%) came from catches made over a range of 20 fath or less.

In the more detailed portion of the study, age distribution, growth rate, and sex ratio were calculated for the 37 through 41 cm size classes to examine the relative importance of these parameters in determining length differences between size classes. All available samples (Table 1) were pooled by size class, regardless of the depth, area, or year of origin.

Retention studies — The data used to study variability in length and other biological parameters came from several different boats. These boats used a variety of gear types and the thoroughness with which they culled their catches to meet the 12-inch (30.5-cm) minimum size limit generally imposed by buyers varied greatly. The resulting differences in retention pattern could cause significant between-catch variability in the mean length of fish landed.

Selectivity differences could also result in between-boat differences in estimated growth rate, since the faster-growing fish would generally be the first caught. As a result, samples from highly selective boats would indicate faster growth than samples from the rest of the fleet.

To evaluate the significance of these effects, the retention patterns of commercial trawlers were examined by comparing length frequencies from drags made using research gear with a 1.5-inch[1] codend liner, and those made when using commercial gear (Table 2). All nets compared to the research gear had 3.5-inch codend mesh, which is almost universally used by Washington trawl vessels in Queen Charlotte Sound. Larger mesh sizes are commonly used in the wing and intermediate portion of the trawl.

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[1] All mesh measurements include one knot.

Raw length frequencies from samples to be compared were smoothed by threes and plotted together (Fig. 2). Next, it was assumed that if 100 fish were caught by commercial gear, the research gear would catch the same number of these commercial-sized fish plus some small fish that would be retained by virtue of its smaller codend mesh.

Consequently, the percentage frequency scale of the research catches were artifically adjusted until the descending limbs of the commercial and research gear types were more or less superimposed, and the percentage retained then calculated for each size group in the ascending limb. This gave a rough approximation of the retention by size group (Fig. 3), which reflects both the vulnerability of each size group to the gear in question and the culling procedure used once the catch was in the boat. Ketchen and Forrester (1966) made similar computations for petrale sole.

Growth studies — The Von Bertalanffy growth model was used to study differences in growth rate between

TABLE 1. Samples used to study age structure, growth, and sex composition of the different size classes.

Geographic origin of sample (ground name)	Date sampled	Depth of sample (*fath*)	No. sampled for length-sex	No. sampled for age	Mean length of sample
		37-cm size class			
SE edge	10/10/66	153	210	210	37.3
SE edge	10/17/66	160	301	100	37.2
SE edge	11/18/66	152	267	101	37.2
SW corner	4/22/68	140–150	285	100	37.4
SW corner	5/1/68	120	271	100	37.2
SE edge	5/15/68	135–140	348	200	37.8
SE edge	5/24/68	100–105	381	100	37.4
SE corner	11/19/68	150	498	200	37.5
Cape Scott	5/5/69	123–125	329	150	37.1
SE corner	7/29/69	100–110	319	200	37.5
		38-cm size class			
Triangle Is.	9/13/67	112–125	207	157	38.9
SE Edge	10/4/67	130–150	339	142	38.0
SE Corner	10/16/67	130–140	331	137	38.6
SW Corner	11/27/67	125–140	339	100	38.3
SE Edge	10/8/68	118–140	313	100	38.6
Cape Scott	4/25/69	100	319	150	38.4
		39-cm size class			
Cape Scott	8/6/68	102–112	285	200	39.5
SW corner	9/22/69	130–145	230	99	39.6
Virgin Rocks	10/20/69	105–113	248	100	39.9
		40-cm size class			
Triangle Is.	11/4/66	112–130	337	95	40.1
NE Corner	8/13/68	87–98	252	200	40.1
Virgin Rocks	9/10/68	115–120	301	100	40.2
SW Corner	8/25/69	100–130	226	200	40.2
Cape Scott	6/12/69	98–100	264	200	40.4
Triangle Is.	10/15/69	115–135	361	200	40.3
		41-cm size class			
Triangle Is.	10/11/66	133–135	379	176	41.3
SW Corner	1/16/68	142–150	257	126	41.7
Triangle Is.	10/23/68	125–135	209	200	41.5

TABLE 2. Information on samples used to examine selection properties of commercial otter trawls. All samples from northern Washington coast, 48°10′–47°40′lat, 125°45′–125°5′long.

	Mesh size (*inches*)					
Boat no.	Wings	Intermediate	Codend	Depth (*fath*)	No. sampled	Date sampled
1. R/V *Commando*	3.5	3.5	3.5	146–154	601[a]	6/3-4/67
vs						
1. R/V *Commando*	3.5	3.5	1.5	144–148	207	6/1/67
1. R/V *Commando*	3.5	3.5	1.5	139–156	401[a]	2/26/68-3/9/68
vs						
2. Commercial vessel	4.0	4.0	3.5	150	298	4/18/68[b]
1. R/V *Commando*	3.5	3.5	1.5	130–206	1298[a]	3/1/69-3/11/69
vs						
3. Commercial vessel	3.5	3.5	3.5	140–200	338	4/14/69[b]

[a] The number of fish in each of the individual samples comprising this total was weighted by the catch rate corresponding to that sample.

[b] Actual date of catch is about a week before sampling date.

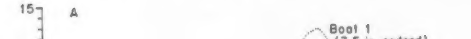

FIG. 2. Length frequencies (sexes combined) for samples (Table 2) used to examine selection properties of commercial trawls.

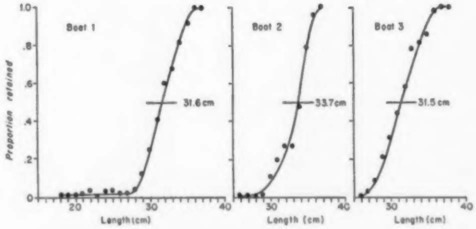

FIG. 3. Approximate selection ogives for boats used in selectivity studies.

size classes. One form of this equation is:

$$l_t = L_\infty (1-e^{-k(t-t_0)})$$

where: l_t = length of fish (*cm*) at age *t* years

L_∞ = theoretical asymptotic length

K = constant expressing the rate of approach to L_∞

t_0 = theoretical age at which $l_t = 0$.

Using this equation, a least squares fit for length at age data (Tomlinson and Abramson 1961) was obtained for both males and females of each size class. Only those age ranges for which a continuous series of data was available with no gaps occurring could be fitted to the model due to restrictions in the computer program employed.[2] The age-groups used to fit each growth curve and the number of age-length observations the curves were based on are shown in Table 3.

Analysis of covariance (Freese 1964) was used to test the significance of differences in growth pattern between size classes. First, growth curves were fitted for each individual size class and the sum of the squared deviations from these fitted lines calculated. Next, the data for the five individual size classes were pooled, and used to fit a single growth curve. The sum of the squared deviations from the single pooled line was then obtained.

Variance between growth lines due to differences in growth pattern between size classes was estimated by:

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[2] Von Bertalanffy Growth Curve Program-II by N. J. Abramson. August 1964. California State Fisheries Laboratory, Terminal Island, Calif.

$$\frac{\text{S.S. from pooled line–S.S. deviations from individual growth lines}}{\text{df for pooled line–df for individual growth lines}}$$

where df = degrees of freedom,

$= (\sum_i \text{number of length observations in the } i^{\text{th}} \text{ age-group}) - 3.$

The hypothesis that there were no significant differences in growth patterns of the different size classes was then tested using the ratio

$$F = \frac{\text{variance between growth lines}}{\text{M.S. for deviations from individual growth lines}}$$

One shortcoming of the method was that the pooled curve could be fit only to that age range for which data from each of the five size classes were available. In the present examples, this meant that age-groups male 9 through 17 and female 9 through 20 (Table 3) were the only ones that could be used to construct a growth curve for all size classes pooled.

Age distributions — The samples listed in Table 1 were used to estimate age composition by sex for each size class. Since the relatively small amount of age data available were subject to more sampling variation than the entire sample of lengths, age–length keys (Gulland 1966) were used. A separate key was computed for males and females from each size class and then used to convert the corresponding length distributions to age distributions.

Results

General distribution of size classes — Table 4 shows the frequency of occurrence of the different size classes by time and depth. The number of samples collected in a given depth and month reflected the annual bathymetric cycle of Pacific ocean perch in Queen Charlotte Sound (Gunderson 1971), whereby the fish move into the sound in April or May, are at the shallowest point in their cycle during July, and return toward deep water starting in about September.

The data in Table 4 indicate that mean length in samples collected from the same year-month-depth strata often differed by 3 cm or more. The mean length of *S. alutus* differed by as much as 3.9 cm in November 1966 (141–160 fath) samples, and 3.1 cm in October 1968 (120–140 fath) samples.

Table 4 also indicates that most fish caught before June belong mainly to the 38-cm and smaller size classes. Of the samples collected January through May, 12% had mean lengths of 39 cm or larger while 56% of the samples collected in the later months fell into this category.

Retention studies — Figure 3 shows that the retention patterns differed somewhat between boats, but that all three boats retained virtually all fish 36 cm and larger. As a result, it can be assumed that variation in the abundance of *S. alutus* larger than 36 cm are not confounded with between-boat variation in retention. It can also be assumed that the growth curves for fish larger than 36 cm (older than 10–12) will not be subject to error caused by differential sampling of small fish. The retention curve of boat two differed somewhat from that of the other boat and it is tempting to attribute this to the different mesh size used in the wings and intermediate section of the trawl of boat two (Table 2). However, the error inherent in the method used to estimate retention patterns and the possibility that there were differences in culling practices between boats make such conjectures spurious.

Growth studies — The growth curves fitted by sex for each size class are shown in Fig. 4. Whether males or females are considered, differences between size classes are just as striking. Growth rate for both sexes increased in a systematic, progressive manner from the 37-cm through the 41-cm size class. The statistical test described above showed that using separate growth curves for each size class significantly reduced unexplained variation in growth

TABLE 3. Number of individual fish and age-groups used to fit sex-specific growth curve for each size class, and the Von Bertalanffy estimates for these curves.

	Size class (*cm*)									
	37.0–37.9		38.0–38.9		39.0–39.9		40.0–40.9		41.0–41.9	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
Ages fitted	6–20	7–21	7–19	7–20	6–18	7–20	5–19	7–21	9–17	9–20
No. fish	754	493	386	296	144	214	397	553	172	288
L	41.66	45.93	41.75	51.68	41.59	47.20	42.95	46.61	42.70	51.56
K	.180575	.138966	.213735	.091446	.223349	.157607	.183561	.180827	.257432	.087466
t_0	–.0256	–.2708	1.6843	–2.4273	1.4618	.8664	.2742	1.5635	2.6935	–5.6468

TABLE 4. Numbers of *S. alutus* samples collected from Queen Charlotte Sound from 1966 through 1969 by month, depth, and size class. ■, 1966; □, 1967; △, 1968; ○, 1969.

Median depth of catch (*fms*)	Size class	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
<100	36													
	37													
	38													
	39													
	40						○		△					2
	41													
100–120	36					□				□				2
	37					□△△		○						4
	38				○	□	○	○	○	□				6
	39								○△	△	○			4
	40						○	△	○	△				4
	41									△				1
	42									△				1
120–140	36													
	37				△	○△								3
	38									○	□□△△	□	■	7
	39									○	○○		■	4
	40									□	○○△	■		5
	41										■△			2
141–160	36		△											1
	37		△△△		△						■■○	■△○		10
	38		△								□	△		3
	39					△					■	■		3
	40												○	1
	41	△										■		2
Total		1	5		3	8	3	3	5	9	17	8	3	65

TABLE 5. Significant range,[a] mean, and variance of lengths, by sex and size class, for the samples listed in Table 1.

Size class (*cm*)	No.	%	Mean length	Significant range	Length variance
37.0–37.9					
♂	2024	63.1	37.0	31–42	7.10
♀	1185	36.9	38.1	32–45	12.72
38.0–38.9					
♂	1130	61.1	37.9	32–42	5.80
♀	718	38.9	39.4	30–46	13.90
39.0–39.9					
♂	320	41.9	37.8	28–43	10.64
♀	443	58.1	41.0	30–47	16.07
40.0–40.9					
♂	745	42.8	38.5	32–43	7.94
♀	996	57.2	41.5	31–46	12.35
41.0–41.9					
♂	348	41.2	39.7	35–49	8.45
♀	497	58.8	42.7	38–49	6.53

[a] Derived by taking the first (or last, depending on which tail) length at which at least 1% of the observations were recorded.

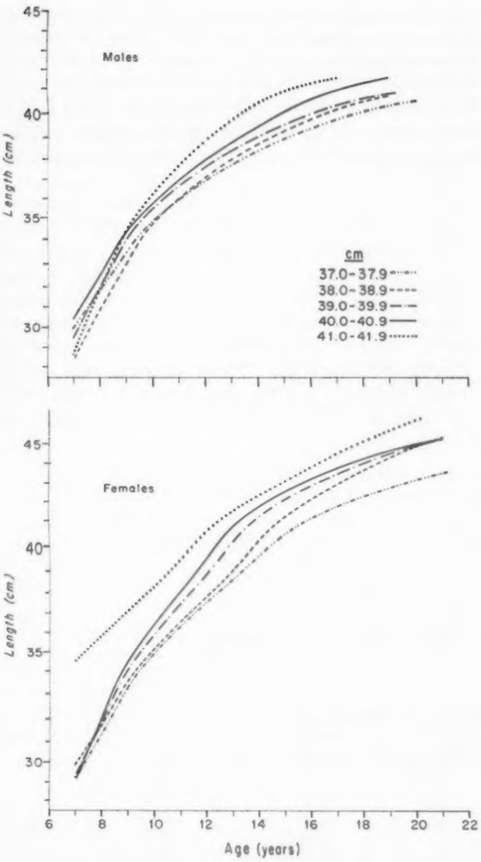

FIG. 4. Mean length at age for male and female Pacific ocean perch from five different size classes. Origin of data is shown in Table 1.

pattern. This was true for both males (F = 6.43 with 12, 30 df) and females (F = 7.70 with 12, 40 df).

Preliminary data from research cruises off Washington indicate that during some months, growth rate may vary with depth. The influence of any depth effect on the results in Fig. 4 would be negligible, however, since careful examination of Table 1 shows that during most months the samples from any given depth seem to be randomly distributed over all available size classes. No serious departure from randomness (i.e. the smallest size classes consistently being constituted from those samples originating in the deepest portion of the bathymetric range) existed.

Age distribution by size class — Age distribution by size class and sex are shown in Fig. 5. Differences in age composition of the five size classes were relatively small, modal age varying no more than 3 years between size groups whether males or females were considered. While the five female age frequencies in Fig. 5 were significantly different at the .05 level ($X^2 = 56.17$ with 36 df), differences between the five male age frequencies were not ($X^2 = 21.17$ with 36 df).

There was a slight tendency for *S. alutus* to be progressively older through the three smallest size classes. This trend was reversed for the larger size classes and the 40- and 41-cm size classes were actually made up of younger fish than those comprising the 39-cm class. Both males and females exhibited the same pattern.

Sex ratios by size class — Since males are shorter-lived and much slower growing than females (Fig. 4 and 5), they should generally be smaller. Table 5 shows that this is indeed the case, the mean length of females being at least 1 cm greater than the mean length of males in the same size class.

Consequently the length differences existing between size classes could easily be generated by differences in the relative proportion of males and females. Table 5 shows that decreases in the percentage of males occur from the 37- through 39-cm size classes and no doubt contribute to the increase in mean length through these classes. On the other hand, sex composition remained quite similar between the three largest size classes and had little bearing on the differences observed in mean length.

Discussion

There was some question as to how much differences in the retention patterns of commercial trawlers influenced the length differences existing between size classes (Fig. 6), and consequently the length variation observed in Table 4. Length distributions for fish 36 cm and larger were not subject to much between-catch variation in retention pattern (Fig. 3) and the progressive increase in the percentage contribution of this group (Fig. 6) from the 37- through 41-cm size classes was clearly the result of increasing abundance on the fishing grounds. The corresponding decline in percent contribution of incompletely retained size groups through this same series could have been influenced by between-catch variation in retention pattern, but it is likely that it was caused primarily by a tendency for small fish to be excluded from aggregations of larger fish.

Even though retention differences and sampling variation probably did not contribute much to the heterogeneity seen in Table 4, it would still be desirable to compare hauls made from the same boat, where no culling was practiced, and where each haul was sampled thoroughly. Three research cruises by the Fisheries Research Board of Canada (Westrheim et al. MS 1968; Harling et al. MS 1969, MS 1970) yielded data that are remarkably well-suited to such comparisons.

During each cruise several replicate hauls were made at the same depth in Queen Charlotte Sound. The mode group composed of adult fish 34 or 36 cm and larger dominated the hauls, accounting for 62, 46, and 48% of the numbers caught per hour and a substantially larger portion of the weight caught during cruises 67–2, 69–3, and 70–1. Even though

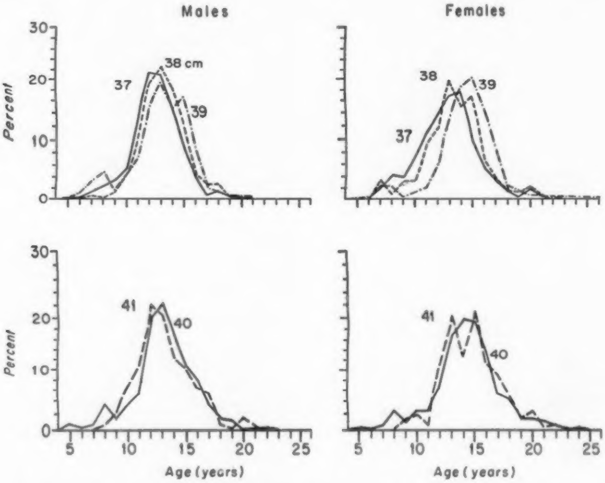

FIG. 5. Percent age composition, by sex, for five groups of market samples, each with a different mean length. Data from 1966 through 1969 samples of Pacific ocean perch from Queen Charlotte Sound.

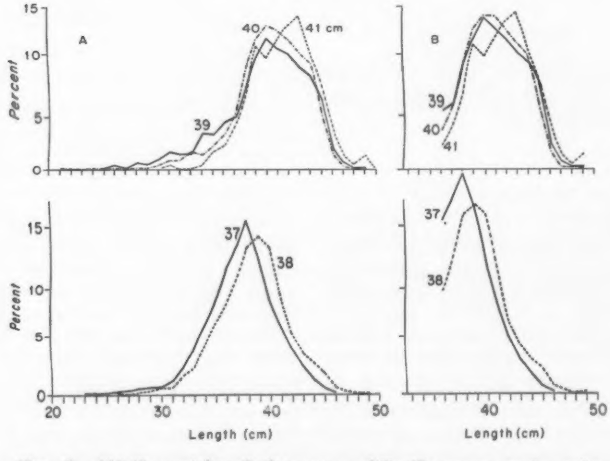

FIG. 6. (A) Percent length frequency of Pacific ocean perch, males and females combined, by size class. (B) Per cent length frequency of fish 36 cm and larger.

several other mode groups were present on the grounds, this was the only one completely represented in the commercial catches and variations in the mean length of fish in this group are somewhat analogous to the previously examined variation between catch samples.

To examine these variations, the mean length of *S. alutus* comprising this mode group was calculated for those hauls made in 100–160 fath that produced 1000 or more fish per hour of trawling. The results (Table 6) show that during both September cruises (67–2 and 69–3) these means commonly varied 2.5 cm or more between hauls, about the same magnitude as the difference existing between September–November commercial samples originating from a common depth. The mean length of those hauls made in 100–119 fath during cruise 69–3 differed by as much as 5.8 cm. A separate one-way analysis of variance was made for the 100–119 fath, 120–139 fath, and 140–159 fath series of hauls made during each of the three cruises and in all 9 cases between-haul differences proved to be significant at the .05 level (F – values ranged from 17 to 511).

It is clear that between-sample length variation for Pacific ocean perch from Queen Charlotte Sound cannot be explained by random variation or between-boat retention differences. Analysis of the biological composition of market samples indicated that most length differences between samples were caused in turn by differences in growth, and that if age-length data were available for each sample taken, they too would show extensive between-sample variability.

The best explanation for these phenomena seems to be that commercially exploited Pacific ocean perch in Queen Charlotte Sound are grouped into

TABLE 6. Mean length within the largest mode group for research hauls made during the Fisheries Research Board cruises (Westrheim et al. MS 1968; Harling et al. MS 1969, MS 1970).

Haul	100–119 fath Mean length within: *34–50-cm group*	Haul	120–139 fath Mean length within: *34–48-cm group*	Haul	140–159 fath Mean length within: *34–46-cm group*
Cruise 67-2					
1	41.0	6	38.7	17	38.5
2	40.9	9	39.3	21	37.9
5	39.3	15	39.9	25	39.2
8	38.6	18	41.6	26	39.0
11	39.3	20	40.6	29	38.7
13	38.4	22	39.2	30	39.4
14	40.3				
19	39.8				
24	40.0				
Cruise 69-3					
	36–48-cm group		*36–46-cm group*		*34–46-cm group*
5	40.6	6	40.3	16	38.2
7	41.2	11	39.9	21	37.8
10	39.4	13	40.0	24	40.2
14	38.2	20	39.8		
19	41.5	31	40.6		
25	44.0	35	39.6		
27	41.7				
34	39.9				
Cruise 70-1					
	38–48-cm group		*36–48-cm group*		*34–46-cm group*
74	41.3	75	39.8	76	37.5
81	40.5	82	39.5	83	37.7
87	41.1	85	40.0	84	37.3
102	40.2	103	39.9		
105	42.4				
107	39.6				

distinct aggregations, each with different biological characteristics. Commercial vessels fishing these aggregations make several trawl hauls before landing, and during the unloading process catches from different hauls are intermixed. Biological differences between aggregations are consequently blurred somewhat by the sampling process, but despite this are great enough to cause significant between-sample variation in length and age-length composition.

Since age and sex composition varied so little between size classes, it does not seem likely that any process involving strict sorting by size (i.e. hydrodynamic sorting or size-selective sampling of the fish on the grounds) takes place in Queen Charlotte Sound. If it did, a wider range of size classes would have been encountered, with the largest of these being made up entirely of old, fast-growing females. The available evidence, therefore, indicates that similarities in feeding behavior and physiology could be as important as hydrodynamics similarities in the formation of the different aggregations. Lebedev (1967) discussed several instances where the behavioral cohesiveness within fish aggregations was sufficient to maintain and increase morphological and physiological differences between aggregations.

The variation in the age-length relation that is associated with the different aggregations makes it imperative that each be sampled in proportion to its abundance if a growth relation representative of all commercial-sized *S. alutus* in Queen Charlotte Sound is desired. If the goal of sampling is restricted to obtaining estimates of age composition and mortality rates, the problem is somewhat simplified. Age composition does not seem to vary drastically between aggregations and pooling random samples of otoliths (or scales) should give usable estimates of age composition. If otolith sampling is stratified by length and an age-length key used to estimate age composition, the results will be less reliable.

Acknowledgments

The author thanks the Washington Department of Fisheries-National Marine Fisheries Service joint aging group, whose members supplied all otolith readings on which the age and growth portions of this paper are based. Port samplers J. Beam and C. Baker collected much of the market sampling data. The cooperation of trawl fishermen and fish wholesalers during market sampling was also greatly appreciated. This study was carried out with funds originating from P. L. 88-309.

Bainbridge, R. 1958. The speed of swimming of fish as related to size and frequency and amplitude of the tail beat. J. Exp. Biol. 35: 109–133.

Freese, F. 1964. Linear regression methods for forest research. U.S. Forest Serv. Res. Pap. FPL 17: 136 p.

Gulland, 1966. Manual of sampling and statistical methods for fisheries biology. Pt 1. Sampling methods. FAO (Food Agr. Organ. UN) Man. Fish. Sci. 3: 58 p.

Gunderson, D. R. 1970. A note on techniques and intensity required for Pacific ocean perch catch sampling. Wash. Dep. Fish. Fish. Res. Pap. 3(2): 29–35.

1971. Reproductive patterns of Pacific ocean perch (*Sebastodes alutus*) off Washington and British Columbia and their relationship to bathymetric distribution and seasonal abundance. J. Fish. Res. Bd. Canada 28: 417–425.

Harling, W. R., D. Davenport, M. S. Smith, U. Kristiansen, and S. J. Westrheim. MS 1970. G. B. Reed groundfish cruise No. 70-1, March 5 to June 18, 1970. Fish. Res. Board Can. Tech. Rep. 205: 82 p.

Harling, W. R., D. Davenport, M. S. Smith, and R. M. Wilson. MS 1969. G. B. Reed groundfish cruise No. 69-3, September 8 to 25, 1969. Fish. Res. Board Can. Tech. Rep. 144: 35 p.

Ketchen, K. S., and C. R. Forrester. 1966. Population dynamics of the petrale sole, *Eopsetta jordani*, in waters off western Canada. Fish. Res. Board Can. Bull. 153: 195 p.

Lebedev, N. V. 1946. Elementary populations of fish. Zoologicleskii Zhurnal, 25(2): 121–135. (Transl. Avail. Fisheries Lab. Lowestoft, Suffolk, Eng.)

1967. Elementary populations of fish. Moscow. 224 p. (Transl. Avail. C.F.S.T.I. Springfield, Va. TT 69-55064)

Lee, R. M. 1912. An investigation into the methods of growth determination in fishes. Con. Perma. Int. Explor. Mer Publ. Circumstance 66: 36 p.

Schaeffer, M. B. 1948. Size composition of catches of yellowfin tuna (*Neothunnus macropterus*) from Central America and their significance in the determination of growth, age and schooling habits. U.S. Fish Wildl. Serv. Fish. Bull. 51(44): 197–200.

Tomlinson, P. K., and N. J. Abramson. 1961. Fitting a Von Bertalanffy growth curve by least squares. Calif. Fish Game 116: 69 p.

Westrheim, S. J. 1970. Survey of rockfishes, especially Pacific ocean perch in the northeast Pacific Ocean, 1963–66. J. Fish. Res. Bd. Canada 27: 1781–1809.

Westrheim, S. J., W. R. Harling, and D. Davenport. MS 1968. G. B. Reed groundfish cruise No. 67-2, September 6 to October 4, 1967. Fish. Res. Board Can. Tech. Rep. 46: 45 p.

NOTES

A Compact Recirculation Unit for the Rearing and Maintenance of Fish

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SCOTT, K. R., AND D. C. GILLESPIE. 1972. A compact recirculation unit for the rearing and maintenance of fish. J. Fish. Res. Bd. Canada 29: 1071–1074.

The use of a compact recirculation system for rearing rainbow trout is described. An 8-month experiment showed that up to 75 kg of fish could be maintained in a healthy condition in a 1600-liter tank using a make-up water rate of only 1.0 liter/min. Temperature, oxygen, *p*H, ammonia nitrogen, and nitrate nitrogen levels were satisfactorily controlled. An average weight gain of 8% per week was achieved with a feed rate of 2% of body weight per day. Fish mortality was insignificant.

SCOTT, K. R., AND D. C. GILLESPIE. 1972. A compact recirculation unit for the rearing and maintenance of fish. J. Fish. Res. Bd. Canada 29: 1071–1074.

Les auteurs décrivent le fonctionnement d'un système compact de recirculation d'eau pour l'élevage de la truite arc-en-ciel. A la suite d'essais qui ont duré 8 mois, il a été démontré qu'on pouvait conserver en bonne condition jusqu'à 75 kg de poisson dans un bassin de 1600 litres ne requérant que 1.0 litre/min d'eau de renivellement. Il a été possible de contrôler adéquatement, durant toute la période d'essai, les niveaux de température et de *p*H et les teneurs en O_2, N ammoniacal et N des nitrates. Un taux d'alimentation de 2% du poids corporel/jour a produit un gain pondéral moyen de 8%/semaine. Les poissons n'ont subi qu'une mortalité insignifiante durant cette période.

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Two methods used to provide water suitable for rearing or maintaining fish are the discard and recirculation systems. Kawamoto (1961), Burrows (1964), and Burrows and Combs (1968) discussed the advantages of each system and the requirements for conditioning water under recirculation. De Witt and Salo (1960) and McCrimmon and Berst (1966) have also described the requirements for recirculation systems in terms of effective filtration, filter backwashing, and aeration. Increasing cost or unavailability of the large volumes of water required to rear fish in a discard system and the need to reduce labor costs by rearing fish at high densities in a capital intensive operation have increased current interest in recirculation systems.

A basic design was established that would use minimum water. Space was conserved by keeping the water conditioning system small in relation to the holding tank. The approach used was to push all components to their limits in order to evaluate the mechanics of the system and to determine the maximum density of fish that could be maintained in a healthy state.

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Recirculation system — The 1600-liter insulated holding tank (Fig. 1, A) was connected to the water conditioning assembly, which was mounted on a 1.85 × 0.64 × 1.98 m high slotted angle frame (F). The recirculation water entered slots (B) in the bottom of the 0.46 m diameter standpipe (C), overflowed through pipe (D) to the suction of centrifugal circulation pump (E), past electronic temperature sensor (T), through flow control valve (G) which held flow at 56.7 liters/min. Water then passed through two successive filters (I), flowmeter (N), combination cooler–heater system (O) and hence through an underwater distribution nozzle (Q) back to the tank. The make-up water entered through flow control valve (X), which held flow at 1.0 liter/min, passed through flowmeter (Y) and directly into the tank. The overflow from the tank flowed downward through slots (B), carrying the heavy wastes down the 33° slope of the drainwell, out the center discharge pipe to drain via adjustable overflow-pipe (Z), which controlled the height of the water in the tank. Tank temperature was controlled by

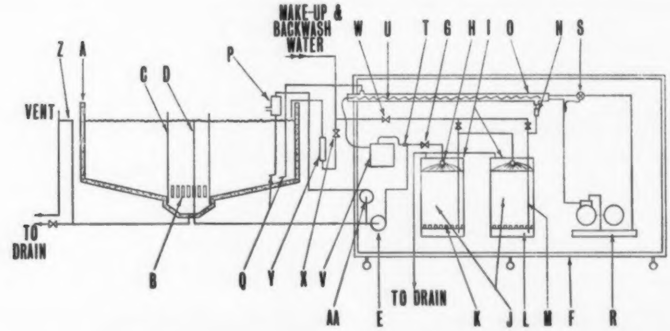

FIG. 1. Recirculation system schematic showing holding tank with standpipe and water-conditioning system components. A, insulated holding tank; B, water-inlet slots; C, standpipe; D, recirculation overflow pipe; E, circulating pump; F, slotted angle conditioning assembly; G, flow control valve; H, water distributors; I, filters; J, filter media; K, nylon distribution nozzles; L, plenum; M, return pipe; N, flowmeter; O, cooler–heater; P, venturi inspirator; Q, discharge nozzle; R, condenser unit; S, refrigerant valve; T, sensor; U, electric heater; V, electronic temperature control; W, backwash flow control; X, make-up flow control; Y, flowmeter; Z, overflow pipe.

temperature control (V), which proportioned power to electric heater (U). Refrigeration was supplied by a 1-hp hermetic condensing unit (R), which fed refrigerant to the cooling coils of cooler–heater (O) via thermostatic expansion valve (S). The system (Scott 1972) was capable of maintaining temperatures within 0.1 C of settings between 2 and 20 C. Oxygenation was achieved by a venturi air inspirator operated by an aeration pump (AA) mounted on the main system and discharging via rotatable underwater nozzle (Q). This method was chosen because of its efficiency and because it did not require a separate subsystem, such as a compressed air line. Compressed air was available and was used in cases of flow failure. A differential pressure switch connected to the venturi system activated a solenoid on flow failure, allowing compressed air to pass through two 30.5-cm airstones installed in the tank.

Analytical methods — Oxygen was monitored with a temperature-compensated dissolved-oxygen meter having an accuracy of 0.1 ppm. Temperature in the tank was continuously recorded on a 7-day chart thermograph and *p*H was measured with a Sargent–Welsh meter. Nitrate nitrogen was analyzed by reduction to nitrite (Wood et al. 1967) and nitrite nitrogen by the method of Bendschneider and Robinson (1952). Ammonium nitrogen was determined by a micromodification of the phenol-hypochlorite method of Solorzano (1969).

Fish loading and feeding rate — The tank was stocked with 2312 rainbow trout, average weight 11.6 g. Weekly weight changes were followed by weighing 30 randomly sampled fish. Total weight of fish was estimated from these data after correcting numbers for removals or deaths and the weight of feed recalculated to maintain the rate of 2% of total body weight. Tank temperature was set at 10 C and recirculation rate at 56.7 liter/min with make-up water input held at 1.0 liter/min.

Results — The oxygen requirements of speckled trout under active metabolism at 10 C was 3.5 ml/hr for a 15-g fish, 8.8 ml/hr for a 45-g fish and 23.7 ml/hr for a 135-g fish (Job 1955). Routine metabolism over a 24-hr period will be less than this by a factor of about 2½. The above figures should be closely applicable to rainbow trout. Oxidation of ammonia to nitrate in the filters required a high oxygen tension and used appreciable amounts of oxygen. The oxygen demand resulting from microbial oxidation of debris trapped in the filters is high, depending on the time after backwash. For example, when the filters carried a high load of debris the oxygen level dropped by 1.9 ppm on passing through filter no. 1 and by 3.7 ppm through filter no. 2. When the filters were clean the drops were 1.3 and 1.6 ppm, respectively.

To calculate the expected oxygen level that can be maintained in a tank at 10 C holding 45 kg of 15-g fish, the oxygen consumption of the fish plus the oxygen demand of the filters is equated to the oxygen supplied by the venturi.

Substituting the saturation concentration Cs = 11.27, the equation to be solved for C (oxygen concentration ppm) is as follows:

$$\frac{(\text{ml O}_2/\text{min} \times (\text{mg/ml}) \times \text{no. of 15-g fish in 45 kg})}{\text{conversion factor to routine metabolism}} + \text{kg/min} \times (\text{C}-5.8) = \text{K}(\text{mg/kg/min/unit conc. gradient}) \times \text{kg water} \times (\text{Cs}-\text{C}) \qquad (1)$$

Substituting in equation 1 and solving for C:

$$\frac{3.5/60 \times 1.43 \times (45{,}000/15)}{2.5} + 56.7 \times (C\text{–}5.8) =$$

$$0.0325 \times 1600 \times (11.27\text{–}C) \text{ giving: } C = 7.5 \text{ ppm } O_2.$$

This value closely approximated the measured values of oxygen. Substituting this value of C in equation (1) we get 100.0 + 96 = 196. This shows that the oxygen demand of the filters is almost as high as that for fish and points out the importance of keeping the filters clean.

Throughout the experiment oxygen levels ranged from 3.5 to 11.9 ppm, remaining generally above 7.0 ppm except when the filters plugged on two occasions. During one of these occasions at 35 days (Fig. 3 no. 2) 105 fish died due to oxygen depletion. Following these incidents, the venturi aeration system was removed from the filtration pumping circuit and connected to a separate pump. No further trouble was encountered throughout the experiment.

Filters — Originally Anthrafilt no. 3 (Blue Coal Corp.) was used in one filter bed and ¼-inch calcite particles in the other. These filtration beds were discarded because the Anthrafilt bound together and made backwashing difficult. Calcite was an effective filtration medium but did not support good rates of nitrification. Both filters were packed at 58 days (Fig. 2 no. 2) with 0.2 m of crushed granite overload with 0.13 m of calcite and the media inoculated with a nitrifying bacterial enrichment culture conditioned to 10 C. These beds were then effective filters, had good backwash characteristics and supported effective nitrification.

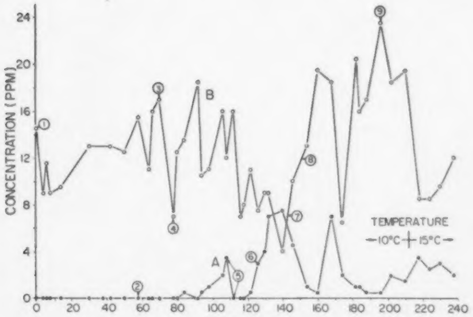

FIG. 2. A, Nitrate nitrogen concentration; B, Ammonium nitrogen concentration; 1, Backwash daily except weekends; 2, Filter media changed from anthrafilt-calcite to granite-calcite combination; 3, Make-up water tripled for 3-day period; 4, Make-up water reduced to 1.0 liters/min; 5, 0.5% calcium propionate fungus treatments; 6, 3% NaCl fungus treatment; 7, Backwash twice weekly; 8, Backwash 3 times weekly; 9, Backwash daily.

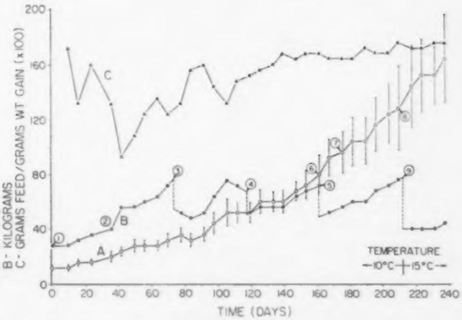

FIG 3. A, Weekly average weight 30 randomly sampled fish showing standard deviation; B, Total fish weight in 1600-liter tank; C, Cumulative feed conversion rate; 1, No. 4 Glencoe feed; 2, 105 fish dead (5% of total); 3, 745 fish removed; 4, 494 fish removed; 5, 342 fish removed; 6, 3/32 inch Glencoe feed; 7, 1/8 inch Glencoe feed; 8, No. 4P EWOS feed: 9, 318 fish removed.

Temperature and pH control — The temperature was set at 10 C and maintained at this level until the last month when it was raised to 15 C. The temperature control system caused no difficulties and performed within specifications throughout the experiment.

The *p*H stayed in a satisfactory range of 6.5–7.5 throughout the experiment, the lowest values occurring when the limestone became covered with debris from the tank.

Biological performance — Fish grew rapidly with minimal mortality. The average weight of the fish increased steadily from 11.6 g to 165.1 g after 238 days. Food conversion was 1.3 g of feed/g weight gain up to a fish weight of 35 g increasing to 1.7 g by the end of the experiment.

The maximum weight of fish the system could maintain was 75 kg, at which density the filters became taxed and the high oxygen demand resulted in a drop of 1.5 to 2.0 ppm in oxygen levels shortly after feeding (Scott 1971). At the 75-kg loading level, abrasions of the dorsal fins which became infected with fungus occurred. Treatment with either 3% NaCl or 0.5% calcium propionate cleared the fungus infection but impaired the nitrification process in the filter bed. The propionate treatment also increased the BOD of the system (Fig. 2 no. 5 and 6). When the loading was lowered to 65 kg, fin abrasions and fungus infections disappeared.

Ammonia and nitrate levels fluctuated widely (Fig. 2). Ammonia levels dropped in response to increased oxygenation, make-up water rate, and backwash frequency or to decreased fish loading. Increased backwash frequency resulted in higher oxygen tension in the filter bed, which enhanced the activity of nitrifying bacteria.

Despite high ammonia levels there were no signs of toxicity in the fish. At 10 C and *p*H 7, only 0.3% of the ammonia is in the unionized form (Wurmann and Woken 1949), furthermore the toxicity of un ionized ammonia is decreased by high oxygen level- (Downing and Merkens 1955). Since a *p*H value near 7 and high oxygen levels were always obtained, high ammonia levels were of no consequence.

Discussion and conclusions — The system successfully supported 75 kg of rainbow trout as an upper limiting weight (compared to 11.3 kg in the McCrimmon and Berst (1966) system), with an average weight gain of 8% per week and with insignificant mortality.

Calculations from Burrows and Combs (1968) on the capacity of a 1600-liter recirculation system indicate a maximum capacity of 50 kg. In their system the volume of the filter beds was roughly equal to that of the holding tanks. Data from Saeki (1958) on the ammonia production by fish and the oxidation capacity of nitrifying bacteria would indicate this system should support less than 10 kg of fish.

The space requirements are small and only 1.0 liters/min of fresh water was added to the system, or approximately one tank volume per day. The compactness of the water conditioning section and the modest water requirements make the design valuable where space and water availability or cost are important factors. In terms of capability for holding or rearing fish, the capital cost of approximately $3000 is modest.

The capacity of the unit could undoubtedly be increased by using larger filter beds that would allow longer times between backwashing and improve ammonia oxidation. The present advantages of compactness and mobility would be lost if the size of the filters were increased by more than 50%. In some operations this might be a useful change.

The filters were the limiting components of the design in that efficiency of backwashing was poor. There is no doubt that not only in the system described here but in other recirculation units, efficient filtration and cleaning of the filter beds are areas where design and testing studies are needed.

Bendschneider, K., and R. J. Robinson. 1952. A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res. 11: 87–96.

Burrows, R. E. 1964. Effects of accumulated excretory products on hatchery products on hatchery-reared salmonids. U.S. Bur. Sport Fish. Wildl. Res. Rep. 66: 12 p.

Burrows, R. E., and B. D. Combs. 1968. Controlled environments for salmon propagation. Progr. Fish-Cult. 30: 123–136.

De Witt, J. W., and E. A. Salo. 1960. An experiment with the complete recirculation of water. Progr. Fish-Cult. 22: 3–6.

Downing, K. M., and J. C. Merkens. 1955. The influence of dissolved oxygen concentration on the toxicity of unionized ammonia to rainbow trout. (*Salmo gairdneri* Richardson). Ann. Appl. Biol. 43: 243–246.

Job, S. V. 1955. The oxygen consumption of *Salvelinus fontinalis*. Univ. Toronto Stud. Biol. Ser. 61, Publ. Ont. Fish. Res. Lab. 73: 39 p.

Kawamoto, N. Y. 1961. Influence of excretory substances of fishes on their own growth. Progr. Fish-Cult. 23: 70–75.

McCrimmon, H. R., and A. H. Berst. 1966. A water recirculation unit for use in fishery laboratories. Progr. Fish-Cult. 28: 165–170.

Saeki, A. 1958. Studies on fish culture in filtered closed-circulation aquaria. Bull. Jap. Soc. Sci. Fish. 23: 684–695. (Transl. from Japanese by Defense Research Board T77J 1964)

Scott, K. R. 1971. Monitoring of fish tank oxygen concentration using a digital recorder. J. Fish. Res. Bd. Canada 28: 1196–1197.

1972. Temperature control system for recirculation fish-holding facilities. J. Fish. Res. Bd. Canada 29: 1082–1083.

Solorzano, L. 1969. Determination of ammonia in natural waters by the phenol hypochlorite method. Limnol. Oceanogr. 14: 799–801.

Wood, G. D., F. A. J. Armstrong, and F. A. Richards. 1967. Determination of nitrate in sea water by cadmium-copper reduction to nitrite. J. Mar. Biol. Ass. U.K. 47: 23–21.

Wurmann, K. von, and H. Woken. 1949. Beitrage zur Experimentelle Untersuchungen uber die ammoniak — und blaüsaurevergiftung. Schweizerische Zeitschrift für Hydrologie Vol. 11: 210–244.

Trials with an Automated Plankton Counter

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FULTON, J. 1972. Trials with an automated plankton counter. J. Fish. Res. Bd. Canada 29: 1075–1078.

An opto-electronic plankton counter-sizer counted samples of zooplankton in seven size classes about six times faster, with greater precision and likely greater accuracy than human sorters. Samples used in the trials were of low diversity, and dominant taxa in each of the seven size classes could be quickly identified under a low-power microscope before machine counts were made. Sample concentrations of less than 3000 organisms per liter were found to be optimal for machine counting. In samples of greater concentration, coincident passage of two or more small organisms caused a bias in favor of the larger size classes.

FULTON, J. 1972. Trials with an automated plankton counter. J. Fish. Res. Bd. Canada 29: 1075–1078.

Un compteur-trieur opto-électronique a dénombré des échantillons de zooplancton de sept classes de grandeur différentes environ six fois plus vite, avec une plus grande précision et sans doute une plus grande exactitude que des trieurs humains. Les échantillons qui ont servi aux essais ne contenaient qu'une petite variété d'organismes, et les taxa dominants de chacune des sept classes de grandeur pouvaient être rapidement identifiés sous le microscope à faible grossissement avant le comptage à la machine. Les concentrations optimales pour le comptage automatique étaient de moins de 3000 organismes par litre. Avec des échantillons de concentration plus élevée, le passage de deux ou plusieurs petits organismes à la fois a faussé les résultats en faveur des classes d'organismes plus grands.

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USE of electronic sizing and counting of phytoplankton is now accepted as a valuable technique intermediate between microscopy and chemical analyses, yielding information not easily obtained by traditional methods. Parsons and LeBrasseur (1970) extended application of size spectra to food chain studies of zooplankton. However, progress in the latter area has been slow due to reliance on microscopy for analysis of zooplankton samples.

Here, the precision, accuracy, and speed of zooplankton counting and sizing with an opto-electric instrument (Cooke et al. MS 1970) are compared with those from traditional microscope analysis.

Methods — The technical details of the optical plankton counter-sizer have been reported by Cooke et al. (MS 1970) and a schematic diagram is shown in Fig. 1. Briefly, a plankton sample containing about 9000 organisms or less is poured to fill a 3-liter mixing reservoir and then allowed to flow through a transparent cell mounted in front of a light beam. The images of the zooplankton are projected linearly on a horizontal array of photocells, which are aligned so as to transmit electrical impulses proportional to the number of photocells covered by the projected images. The electrical impulses so generated are recorded in an electronic logic circuit.

In the present model, zooplankton were counted in seven size categories as follows: 0.5–0.0 mm, 1.1–1.5 mm, 1.6–2.5 mm, 2.6–4.0 mm, 4.1–8 mm, 8.1–15 mm, > 15 mm. Particles smaller than 0.5 mm were excluded

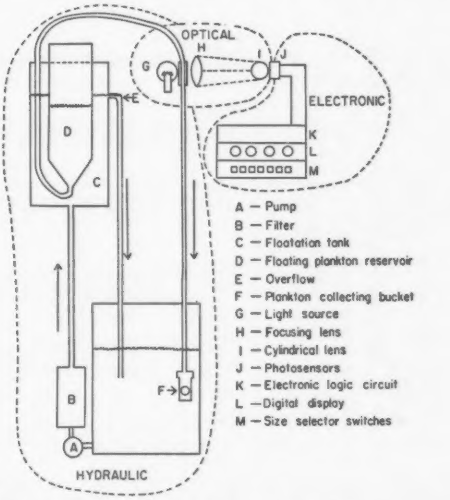

FIG. 1. Block diagram of automated plankton counter.

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TABLE 1. Replicate counts of two zooplankton samples. Raw data is included to demonstrate the erratic counts made by human counters.

(a) Machine sorts of sample 1									(b) Visual sorts of sample 1								
	Size class in mm									Size class in mm							
Count no.	.5/1.0	1.1/1.5	1.6/2.5	2.6/4.0	4.1/8.0	8.1/15	>15	Total	Counter no.	.5/1.0	1.1/1.5	1.6/2.5	2.6/4.0	4.1/8.0	8.1/15	>15	Total
1	73	134	179	110	887	31	8	1422	1	30	171	111	48	915	50	12	1337
2	95	114	179	112	876	40	8	1424	1	45	99	96	54	1001	43	11	1349
3	72	117	189	113	894	34	7	1426	2	0	69	108	99	661	51	17	1065
4	74	135	190	98	901	31	6	1435	2	0	48	177	60	667	54	11	1017
5	70	129	177	110	902	33	7	1428	3	0	59	185	102	1034	72	14	1466
6	91	126	192	111	896	33	7	1456	3	0	40	187	54	757	63	13	1114
7	91	122	177	116	894	26	6	1426	4	13	107	199	81	878	30	9	1318
8	84	119	187	111	892	32	7	1432	4	11	87	170	71	908	47	9	1303
9	79	141	179	120	891	32	9	1451	5	3	72	216	84	815	43	9	1242
10	96	152	197	131	900	32	7	1515	5	15	36	144	93	1017	39	8	1352
$\bar{x}$	83	129	184	113	893	32	7.2	1442	$\bar{x}$	11.7	79	165	74	865	49	11.3	1256
SD	10.1	11.9	7.24	8.39	7.70	3.44	.92	28.2	SD	15.2	40	38	20	136	12	2.8	145
SE	3.1	3.6	2.2	2.5	2.3	1.0	0.3	8.5	SE	4.6	12.1	11.5	6.1	41.2	3.6	0.85	43.9
RSD	.12	.09	.04	.07	.01	.11	.13	.02	RSD	1.3	0.51	0.23	0.27	0.16	0.24	0.25	0.12
1	97	87	126	93	756	21	5	1185	1	45	89	135	63	714	38	7	1091
2	82	115	174	98	755	18	5	1247	1	75	120	84	81	868	39	7	1274
3	102	121	166	94	765	17	4	1261	2	54	183	30	30	571	45	8	921
4	98	134	170	93	762	16	5	1278	2	0	45	126	90	718	32	6	1017
5	100	124	170	102	747	20	5	1268	3	0	72	136	74	682	47	8	1008
6	101	119	144	98	728	20	5	1215	3	0	47	125	78	754	50	4	1058
7	82	111	168	103	747	19	4	1234	4	7	49	168	73	764	31	5	1097
8	92	103	154	95	749	18	4	1215	4	8	86	126	52	711	33	5	1021
9	83	119	173	95	771	17	4	1262	5	12	51	129	66	810	21	4	1093
10	82	127	171	98	763	17	5	1263	5	12	48	153	87	917	29	4	1250
$\bar{x}$	92	117	162	97	754	18.3	4.6	1244	$\bar{x}$	21.3	79	121	69	751	36	5.8	1082
SD	8.7	12.5	15.0	3.5	12	1.6	.51	31.4	SD	26.7	44	39	18	98	9	1.6	108
SE	2.6	3.8	4.5	1.1	3.6	.54	.16	9.61	SE	8.1	13.3	11.8	5.5	29.7	2.73	0.48	32.7
RSD	.10	.11	.10	.04	.02	.09	.11	.03	RSD	1.26	0.56	0.32	0.25	0.13	0.25	0.28	0.10

because they were mostly detritus or fragments of organisms.

In order to compare the performance of the machine with that of human counters, two samples of low diversity were chosen. These samples were preserved in 4% formalin for 3 months prior to analysis. Before the test began all coelenterates, large amphipods, and squid, which might clog the counting cell of the machine, were removed from the samples. Each sample was marked with a code number which was changed after each count, so that counters had no way of knowing when they were making replicate counts of the same sample. The two samples were counted twice by each of five experienced zooplankton counters and then each sample was machine-counted 10 times.

The five counters, following laboratory routine, were instructed to count all the zooplankton organisms in each of the machine size classes in 1 hr or less. This involved pouring the sample into a transparent Bogorov counting tray with a background grid marked in 1-mm units. All organisms larger than 8 mm were counted in total. The tray was then placed under a dissecting microscope (low power, ×6) and one row of the tray (one-third) was counted for organisms 2.5–8 mm. The magnification was then increased (×12) and four random fields were counted for organisms smaller than 2.5 mm (four fields covered one-tenth of the area of the counting tray). At the beginning of each count the counter could elect to subsample the original sample using the Folsom plankton splitter.

In order to relate precision and accuracy to sample size, one large sample was subsampled seven times using the Folsom splitter. Each subsample was one-half the size of the preceding sample. The seven subsamples were then counted four times by machine.

Because long, thin animals might tend to fold when passing through the counting cell, 90 chaetognaths ranging from 15 mm to 22 mm were manually sorted from a sample and counted by the machine 10 times. Visual counts were made both before and after machine counts.

The mean, standard deviation, standard error, and relative standard deviation were calculated for replicate counts by humans and machine (Table 1).

Comparison of visual and mechanical counting — For machine counts of the two zooplankton samples, the relative standard deviation (RSD) ranged from 0.02 to 0.13; for visual counts the RSD ranged from 0.13 to 1.30 (Table 1). All machine counts showed less variability than visual counts, higher counts in the two smallest size classes, and lower counts in the two largest size classes.

High machine counts in the smallest size classes are explained by the inability of the machine to differentiate between organisms and fragments of organisms which the human counter rejects as detritus. The lower machine counts in the larger size classes are explained by the tendency for chaetognaths either to fold and be counted in a smaller size class, or to pass through the cell in clumps of two or more animals giving one count in the >15 size class. Both tendencies were apparent when only chaetognaths were counted. Machine counts of successive subsamples made with the Folsom plankton splitter showed that the total count decreased as the concentration of organisms increased (Table 2). The decrease of total counts was accompanied by an increased count in the large size classes, due to coincident passage of two or more organisms through the counting chamber, counted as one larger organism. Coincidence did not affect precision but did affect accuracy in the larger size classes when concentrations were greater than 3000 organisms per liter.

TABLE 2. Machine counts with increasing concentration of zooplankton sample. Each count is the mean of four machine counts. Underlined counts are high because coincident passage of two or more small organisms appear as one large organism.

Subsample size	Size class in *mm*							Total Subsample counts
	0.5 1.0	1.1 1.5	1.6 2.5	2.5 4.0	4.1 8.0	8.1 15	>15	
1/64	76±.22[a]	38±.15	177±.05	647±.01	689±.03	2±.67	0	1,600
1/32	102±.15	56±.14	280±.01	1003±.004	1113±.04	7±.28	0	2,561
1/16	252±.23	142±.15	600±.02	2003±.01	2066±.02	17±.31	1	5,080
1/8	936±.19	267±.08	1026±.02	3995±.04	3955±.06	73±.19	1±1.01	10,252
1/4	3421±.04	566±.05	1737±.03	7055±.02	6774±.03	273±.05	6±.30	19,832
1/2	11280±.06	1192±.04	2390±.07	11685±.04	10842±.05	985±.08	50±.14	38,424
1	30957±.01	2088±.01	3071±.04	17250±.03	14949±.03	3010±.16	395±.07	71,720

[a] Relative standard deviation.

TABLE 3. Example of final data sheet from sample #1. Visual scan is with binocular microscope.

Size Class (*mm*)	Particle Count	Visual Scan	Organisms
.5–1.0	83	75% fragments	62 detritus
		25% *Parathemisto*	21 *Parathemisto*
1.1–1.5	129	98% *Parathemisto*	126 *Parathemisto*
		2% *Scolecithricella*	3 *Scolecithricella*
1.6–2.5	184	75% *Parathemisto*	138 *Parathemisto*
		25% *Calanus pacificus*	46 *C. pacificus*
2.6–4.0	113	50% *Parathemisto*	56 *Parathemisto*
		50% *Calanus pacificus*	57 *C. pacificus*
4.1–8.0	893	99% *Calanus plumchrus* V	884 *C. plumchrus* V
		1% *Parathemisto*	9 *Parathemisto*
8.1–15.0	32	all *Sagitta elegans*	32 *S. elegans*
>15	7	all *Sagitta elegans*	7 *S. elegans*

Discussion — Comparison of the means of machine and of visual counts (Table 1) indicates a close relation except for the consistent bias of the machine counts in the smallest size class. A visual scan of the sample is necessary to determine the ratio between organisms and detritus; a visual scan is also necessary when two or more species occur in the same size class (e.g. Table 3, 1.6–2.5 mm). Although the similarity between machine and visual counts does not guarantee accuracy, it indicates that results by the two methods are either accurate or consistently biased.

One person, using this machine, can process six preserved samples containing about 3000 organisms per liter every hour, counting number of organisms in each size class. With low diversity samples (such as the subarctic Pacific samples used in these trials) an experienced operator can identify with low-power microscopy the most abundant species in each size class while the next sample is being run through the machine. Without the machine an experienced counter can process about one sample per hour.

In the model of the machine tested, the inside diameter of the counting cell was 3 mm. Organisms which have their smallest dimensions greater than 2.5 mm (such as medusae, salps, and pelagic shrimps) plug the machine and must therefore be removed from the sample. In practice this is relatively easy. Large, flexible organisms, such as chaetognaths, may be removed with a sieve and counted separately, if greater accuracy is required for this type of organism. The most serious problem encountered was dealing with samples clogged and matted with senescent phytoplankton. However, since this kind of sample is not likely to be quantitative, due to net clogging, the effort required to count it with accuracy and precision would be wasted.

Length-frequency data such as that obtained by use of the automated plankton counter may be used to study the biology of fishes feeding on zooplankton (e.g. Parsons and LeBrasseur 1970) in much the same way as Coulter Counter data has been used to study zooplankton grazing on phytoplankton (Parsons et al. 1967). Properly used, the automated plankton counter can be a useful tool in the study of marine food chains.

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COOKE, R. A., L. D. B. TERHUNE, J. S. FORD, AND W. H. BELL. MS 1970. An opto-electronic plankton sizer. Fish. Res. Board Can. Tech. Rep. 172: 40 p.

PARSONS, T. R., AND R. J. LEBRASSEUR. 1970. The availability of food to different trophic levels in the marine food chain, p. 325–342. *In* J. H. Steele [ed.] Symposium on marine food chains, Aarhus, 1968, Oliver and Boyd, Edinburgh.

PARSONS, T. R., R. J. LEBRASSEUR, AND J. D. FULTON. 1967. Some observations on the dependence of zooplankton grazing on the cell size and concentration of phytoplankton blooms. J. Oceanogr. Soc. Jap. 23: 10–17.

Length–Weight Relationship for Pomfret

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MANZER, J. I. 1972. Length–weight relationship for pomfret. J. Fish. Res. Bd. Canada 29: 1079–1081.

The length–weight relationship for 298 pomfret (*Brama japonica*) ranging in fork length from 30 to 49 cm, and caught in 1956 and 1957 in the Gulf of Alaska by gillnets varying in mesh size from 2½ (63 mm) to 5¼ inches (133 mm) was examined. Covariance analysis of the data indicated that within years the length–weight relationship did not differ between males and females; and, on the average, both males and females of a particular length were significantly heavier in 1956 than in 1957. Allometric equations for each year based on data for sexes combined are considered more appropriate than a single equation based on pooled data. The equations relating weight in kilograms to length in centimeters, for 1956 and 1957, respectively, are

$$W = 0.0002068L^{2.774} \text{ and } W = 0.0001539L^{2.641},$$

and apply to the lower third of the known size range for pomfret in the Gulf of Alaska.

MANZER, J. I. 1972. Length–weight relationship for pomfret. J. Fish. Res. Bd. Canada 29: 1079–1081.

L'auteur examine la relation longueur–poids de 298 castagnoles (*Brama japonica*) de 30 à 49 cm de longueur à la fourche, capturées en 1956 et 1957 dans le golfe d'Alaska à l'aide de filets maillants de mailles variant de 2½ à 5¼ pouces (63–133 mm). L'analyse de la covariance démontre que, dans une même année, la relation longueur–poids des mâles ne diffère pas de celle des femelles; de plus, pour une longueur donnée, mâles et femelles sont en moyenne significativement plus lourds en 1956 qu'en 1957. Une équation allométrique, établie pour chaque année à partir d'observations sur les deux sexes combinés, est préférable à une seule équation basée sur des données mises en commun. La relation entre le poids en kg et la longueur en cm pour les années 1956 et 1957 s'exprime par les équations suivantes, respectivement:

$$W = 0.0002068L^{2.774} \text{ et } W = 0.0001539L^{2.641},$$

valables pour le tiers inférieur de la gamme des longueurs connues des castagnoles du golfe d'Alaska.

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INCIDENTAL catches of pomfret (*Brama japonica*) made during high seas salmon studies in the Gulf of Alaska in the late 1950s suggest that the species constitutes a substantial unexploited resource. Except for limited information on distribution and feeding (Pinckard 1957; Neave and Hanavan 1960; Hitz and French 1965; J. I. Manzer unpublished data) very little is known about the biology of pomfret in this region. This paper reports on the length–weight relationship for individuals in the lower part of the known size range for the species, an expression useful in population dynamics and growth studies and for comparing body form of different groups of fish.

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Materials and methods — Data used in this study were obtained from a sample of 116 pomfret caught in 1956 and 182 caught in 1957. The fish were caught at several locations in the Gulf during the summer within the top 20 ft (6 m) of the surface with gillnets constructed from 2½ (63 mm), 3¼ (82 mm), 4½ (114 mm), and 5¼ inch (133 mm) nylon webbing (stretched measure). The ratio of the respective gillnets in 1956 was 1:1:1:3; in 1957, 1:1:3:1.

Preservation and sampling methods used in each year in general were similar. Shortly after capture the fish were brine-frozen aboard the research vessels. Later, in the laboratory, fish were thawed and each was routinely sampled for sex, fork length to the nearest centimeter, and round weight to the nearest ounce. Weight data were later converted to kilograms. The fish sampled ranged in length from 33 to 49 cm in 1956; from 30 to 45 cm in 1957.

The relationship between length and weight for males and females was determined separately for each year using data for all fish, converting the values for both variables to common logarithmic values, and fitting a straight line to the logarithmic values by the method of least squares. The differences in the length–weight relationship between sexes and between years were tested during the one-way analysis of covariance computer program COV2 written in Fortran (1130) by the Computer Service, Biological Station, Nanaimo, B.C.

Results and discussion — The relationships between length and weight for males and females separately in 1956 and 1957 are illustrated as an arithmetic plot in Fig. 1. In each case, the weight for each length group represents either the weight of a solitary individual or the mean weight of a group of fish, if two or more fish of a particular length were sampled. This method of illustrating data does not show individual deviations from the mean for size groups having more than one fish, but was adopted for purposes of convenient comparison of the general relationship between sexes and years in a single figure. The relationships apparently are expressed satisfactorily by the allometric equation, $W = aL^b$, where W = weight, L = length, a and b are constants, or logarithmically by the formula $\log W = \log a + b \log L$.

The regression estimators are presented in Table 1.

The results of covariance analysis (Table 2) indicates:

1) Within years, the slope of the regression, b, and the intercept a, of the regression lines for each sex were not significantly different. 2) Between years, b for each sex was not significantly different. 3) Between years, the intercept of the regression lines for both males and females differed significantly.

The reason for the demonstrable difference between years in the elevation of the regression lines for either sex remains obscure. The size range and the dominant length classes in 1957 were smaller than in 1956, suggesting that the change in the ratio of $4\frac{1}{2}$- to $5\frac{1}{4}$- inch mesh gillnet from 1:3 in 1956 to 3:1 in 1957 may be operating in the form of gear selectivity. However, there is some reason to question gear selection as the sole agent for the observed difference in the elevation of the regression lines when it is recognized that, throughout the size range common to each year's catch, fish of a particular length were heavier in 1956 than in 1957 (Fig. 1). This difference in relative condition suggests that environmental factors promoting growth may also be contributory. It is of some interest to note from data presented by LeBrasseur (MS 1965) that

TABLE 1. Data for regression of log weight on log length for male (M) and female (F) pomfret sampled in 1956 and 1957.

Sex	No. sampled	Mean length	Mean weight	*a*	*b*
		1956			
(M)	54	1.6018	0.1277	−4.1887	2.6947
(F)	62	1.5968	0.1130	−4.4637	2.8662
(M+F)	116	1.5991	0.1198	−4.3156	2.7736
		1957			
(M)	100	1.5380	−0.1232	−4.2652	2.6932
(F)	82	1.5302	−0.1480	−3.8922	2.4468
(M+F)	182	1.5344	−0.1344	−4.1872	2.6412

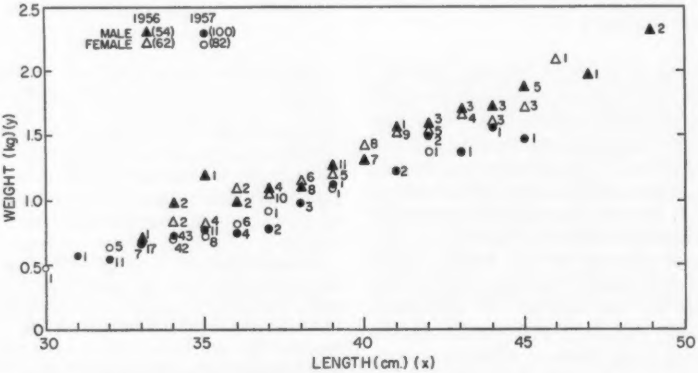

FIG. 1. Relationship between length and weight in male and female pomfret in the Gulf of Alaska in 1956 and 1957.

TABLE 2. Analyses of covariance for linear regression of weight on length of male and female pomfret within and between years. Significance level: ** = >0.01.

Source of variation	Degree of freedom	F
Males versus females, 1956		
$^bM = {}^bF$	1	0.53
$^aM = {}^aF$	1	0.01
Pooled residual	112	
Males versus females, 1957		
$^bM = {}^bF$	1	0.99
$^aM = {}^aF$	1	0.73
Pooled residual	178	
Males, 1956 versus 1957		
$^b56 = {}^b57$	1	0.00
$^a56 = {}^a57$	1	59.70**
Pooled residual	150	
Females, 1956 versus 1957		
$^b56 = {}^b57$	1	2.62
$^a56 = {}^a57$	1	61.27**
Pooled residual	140	

the standing crop of zooplankton in the upper 150 m in the Gulf of Alaska in 1956 was found to be 1.6 times that in 1957 (123 g/1000 m^3 compared to 77 g/1000 m^3).

Because of the difference in the regression intercepts in the 2 years over the size range examined, it is tentatively concluded that grouping all data to provide a single allometric equation relating length (cm) to weight (kg) may not be justified. Provision of equations for each of the 2 years based on pooled data for the sexes would appear more appropriate. The resulting equations on this basis are:

$$1956: W = 0.0002068L^{2.774}$$
$$1957: W = 0.0001539L^{2.641}$$

Pomfret off the British Columbia coast are known to grow to 4 ft (1.2 m) in length (Clemens and Wilby 1961). The length–weight relationship described here are, therefore, for fish in the lower third of the length range. Reexamination of the derived relationship for both sexes may be necessary in the case of considerably larger individuals, when sexual dimorphism can be more pronounced.

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CLEMENS, W. A., AND G. V. WILBY. 1961. Fishes of the Pacific coast of Canada. (2nd ed.) Fish. Res. Board Can. Bull. 68: 443 p.

HITZ, C. R., AND R. R. FRENCH. 1965. Occurrence of pomfret (*Brama japonica*) in the northeastern Pacific Ocean. Fish. Ind. Res. 3: 1–7.

LEBRASSEUR, R. J. MS 1965. Biomass atlas of net zooplankton in the northeast Pacific Ocean, 1956–1964. Fish. Res. Bd. Canada MS Rep. 201: 14 p. + 247 fig.

NEAVE, F., AND M. G. HANAVAN. 1960. Seasonal distribution of some epipelagic fishes in the Gulf of Alaska region. J. Fish. Res. Bd. Canada 17: 221–233.

PINCKARD, W. F. 1957. Pomfret off the British Columbia coast. Fish. Res. Board Can. Pac. Progr. Rep. 109: 6–8.

Temperature Control System for Recirculation Fish-Holding Facilities

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The self-contained conditioning unit included heating, refrigeration, filtration, and aeration devices on a caster-mounted frame. Heating and cooling were performed in a stainless steel combination cooler-heater unit. Heating is produced by an electric resistance element and cooling by a water-cooled hermetic refrigeration compressor. Temperatures were maintained within ±0.06 C degree of set point between 2 and 20 C in two 200-gal tanks using a modulating electronic temperature controller.

Scott, K. R. 1972. Temperature control system for recirculation fish-holding facilities. J. Fish. Res. Bd. Canada. 29: 1082–1083.

L'unité de conditionnement autonome comprend des dispositifs de chauffage, de réfrigération, de filtrage et d'aération sur châssis à roues pivotantes. Une unité en acier inoxydable assure à la fois le chauffage et le refroidissement. Le chauffage est produit par une résistance électrique et le refroidissement, par un compresseur réfrigérant refroidi à l'eau. Un contrôle électronique modulateur permet le maintien des températures à ±0.06 C d'un point fixe entre 2 et 20 C dans deux bassins de 200 gallons.

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Reliable temperature control is important in live fish holding and rearing in fisheries laboratories. Different techniques have been used in the past, such as (a) hot and cold water mixing valves, connected to a large central water source, or (b) unitized drop-in cooling units and immersion heaters. Disadvantages of the former are cumbersome piping, high capital cost, and relative inflexibility in tank arrangement. The latter requires several cooling units and heaters along with controls, all mounted inside the tank, thus interfering with tank use and complicating management.

The system presented here can be easily adapted to existing installations and allows temperatures to be controlled to ±0.06 within the range 2–20 C.

General arrangement[1] — For maximum flexibility the components were mounted on a portable 6 ft × 2 ft × 6-½ ft high slotted angle frame (Fig. 1). Water was withdrawn from the tank to be serviced (Fig. 1, A) by a high capacity centrifugal pump (B), and first passed through two successive biological filters (C) to remove debris, control *p*H, and promote rapid nitrification of ammonia produced by the fish (Scott and Gillespie 1972). The filters also retard slime formation in the combined cooler-heater and thus maintain a high heat transfer efficiency. The water then passed through the cooler-heater (D) to maintain the desired water temperature as selected on controller (E), then through an inspirator aeration unit and finally back to the tank. The water was discharged into the tank near the bottom through a rotatable nozzle which ensured good mixing of the air and water and allowed any desired rotational velocity of the water in the tank.

Cooler-Heater — The combined shell and multi-tube cooler-heater is made from type 316 stainless steel to minimize toxic effects. It has an outer shell 2 inch outside diameter × 0.065 inch thick × 8 ft long, inside which are nested seven ½-inch outside diameter × 0.035-inch thick tubes. The ends of the cooler-heater extend beyond the mounting frame to facilitate connections and servicing. Refrigerant circulates through the outer ring of six connecting tubes. The seventh central tube extends through the cooler-heater and is open at both ends to permit easy replacement of the 0.42 inch outside diameter "Incoloy" (30 % Ni, 20 % Cr) sheathed electric immersion heater without shutting down the system or opening the heat exchanger. Insulation around the cooler-heater minimizes heat transfer and helps to eliminate condensation at low operating temperatures. The cooling section can transfer 5550 P.C.U. (pound calorie units) per hr with an L.M.T.D. (log mean temperature difference) of 8.3 C between the water and refrigerant when circulating 15 gal/min (567 liters) of water; the heating

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[1] Complete engineering details for all components are available from the author.

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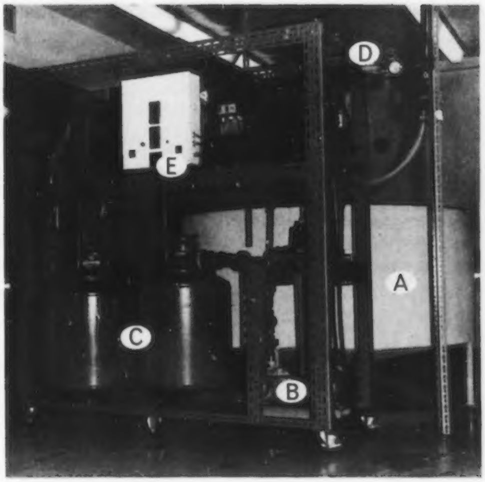

FIG. 1. Caster-mounted water-conditioning assembly connected to fish tank. A, 420-gal tank; B, centrifugal pump; C, biological filters; D, combined cooler-heater; E, temperature controller.

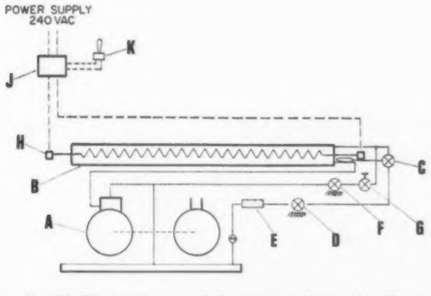

FIG. 2. Refrigeration and heating schematic diagram. A, water-cooled compressor; B, cooler-heater; C, thermostatic expansion valve; D, solenoid valve; E, filter dryer; F, hot gas solenoid; G, limiting orifice hand valve; H, electric heater; J, electronic temperature controller; K, thermistor sensor.

TABLE 1. Average temperature and standard deviations at various depths and distances from center of tank.

Set point (*C*)	Tank (*avg*)	6-inch depth	12-inch depth	18-inch depth	24-inch depth	10-inch radius	16-inch radius
	N = 24	6	6	6	6	12	12
20	19.44±0.05	19.44±0.05	19.42±0.05	19.45±0.04	19.44±0.07	19.45±0.04	19.42±0.06
18	17.49±0.06	17.47±0.06	17.50±0.07	17.50±0.03	17.50±0.07	17.51±0.05	17.47±0.06
16	15.70±0.04	15.70±0.05	15.69±0.04	15.71±0.03	15.70±0.05	15.71±0.03	15.69±0.05
14	14.13±0.05	14.12±0.06	14.13±0.05	14.14±0.04	14.13±0.06	14.14±0.04	14.12±0.05
12	12.14±0.03	12.14±0.04	12.14±0.02	12.15±0.02	12.15±0.05	12.15±0.02	12.14±0.05
10[1]	10.37±0.05	10.36±0.09	10.36±0.03	10.37±0.02	10.39±0.05	10.39±0.03	10.35±0.06
10[2]	9.92±0.03	9.94±0.02	9.91±0.04	9.91±0.01	9.92±0.04	9.92±0.02	9.91±0.03
8	8.02±0.03	8.03±0.02	8.01±0.02	8.00±0.03	8.03±0.04	8.02±0.03	8.01±0.03
6	6.29±0.03	6.31±0.01	6.28±0.04	6.26±0.03	6.30±0.03	6.29±0.03	6.29±0.04
4	4.17±0.06	4.20±0.03	4.17±0.05	4.12±0.08	4.19±0.04	4.18±0.05	4.16±0.07
2	2.23±0.06	2.27±0.03	2.23±0.06	2.18±0.08	2.22±0.03	2.23±0.05	2.23±0.06

[1] Low cooling rate.

[2] High cooling rate.

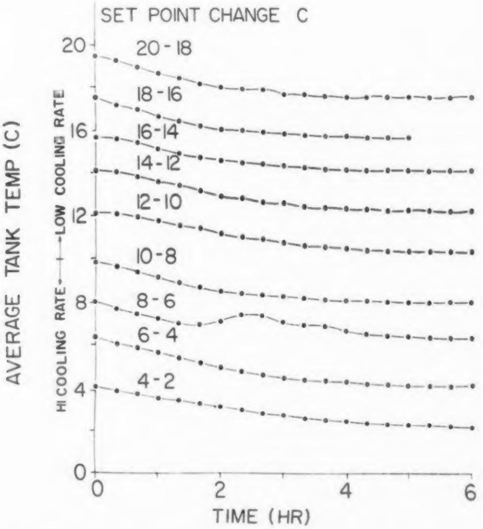

FIG. 3. Average tank temperature as a function of time following 2 C step changes from 20 to 2 C.

section can transfer 5500 P.C.U./hr at a heating density of 3.2 w/square inch. Since heating and cooling capabilities are equal, any temperature between maximum heating and maximum cooling can be achieved.

Temperature control — The cooling system (Fig. 2) consists of 1-hp hermetic water-cooled refrigeration compressor (A), feeding liquid refrigerant to the cooling section of the cooler-heater (B), via a thermostatic expansion valve (C), solenoid valve (D), and a filter-dryer (E). A hot-gas line from the compressor discharge feeds through a hot-gas solenoid (F) and a limiting orifice hand valve (G) and joins the liquid line downstream of the expansion valve before entering the cooling coils.

The electric heater (H) is controlled by a solid state modulating electronic temperature controller (J). The output of a Wheatstone bridge is automatically adjusted by a thermistor sensor (K) in the pump discharge and an adjustable set potentiometer connected in adjacent legs of the bridge. The bridge output then controls the firing angle and hence the power output of two SCRs (silicon-controlled rectifiers) connected in inverse parallel to give a full wave output to the heater. The controller has an adjustable proportional band width from 2 to 10% of the setpoint range and its setting determines the water temperature level at which full power to the heater element will gradually begin to decrease in proportion to the temperature difference between the water temperature and the set point. Safety switches turn off either the heater or refrigeration compressor should independently adjusted limits be exceeded. The heater also shuts off automatically if water flow is interrupted. Similarly, pump and refrigeration compressor motors are protected by overload devices.

Twenty-four copper constanton thermocouples were precalibrated against a precision thermolinear thermometer and calibration constants calculated for each thermocouple to give an accuracy of 0.05 C over the entire operating range.

To evaluate the performance of the temperature control system, the unit was connected to two 200-gal, 4-ft diameter × 2½-ft high insulated fiberglass tanks equipped with plastic covers. In one tank at each of four depths there were groups of six precalibrated thermocouples. For each group of thermocouples, three were evenly spaced at a radius of 10 inches and three at a radius of 16 inches from the center. Make-up water was ¼ gal/min (0.95 liters) and varied in temperature from 3.9 to 4.5 C. Recirculated and make-up water were divided equally between the two tanks.

The thermocouples were connected to a multichannel digital datalogger and the system started. Information from each thermocouple was recorded automatically every 10 min for 6 hr using set temperatures of 20 to 2 C in 2 C intervals. All data were transmitted to the University of Manitoba's IBM 360/65 computer for calculation and analysis using prewritten PL/1 programs (Scott 1971).

Table 1 shows that average tank temperature can be held at any desired value between 2 and 20 C with a maximum standard deviation throughout the tank of ±0.06 C. Temperature at any depth or at either radius from the center did not vary more than ±0.09 C, indicating good mixing both vertically and horizontally. Figure 3 shows the plot of average tank temperature as a function of time following successive 2 C step changes in set point from 20 to 2 C. About 3–4 hr were required for the entire tank to reach the new settings. The longest time was required for a temperature drop from 4 to 2 C since system capacity is being approached at this level.

Discussion — The system has been used successfully to rear rainbow trout under accurately controlled temperatures in a 420-gal tank over an 8-month period (Scott and Gillespie 1971). It is compact, reliable, accurate, easily movable, and has an operating temperature range which makes it suitable for use as an aquatic life support system for rearing and maintaining fish for research purposes. The ability to reach and maintain temperatures below 2 C makes the system especially valuable for low-temperature investigations, since most other systems cannot reach these levels due to the danger of freeze-up. Separate tests show that the unit can maintain 0.8 C indefinitely without danger of freeze-up. The use of a water-cooled refrigeration machine results in most of the rejected heat being sent to drain, thus minimizing the amount of heat released to the room and reducing air-conditioning expenses. The system efficiency is further increased by "staging" the refrigeration capacity. The manual limiting hand valve is adjusted to impose an artificial cooling load of about 50% of compressor capacity giving selectable high or low cooling rates by manually switching the hot gas solenoid on or off. This will in turn reduce total power consumption when the set temperature is near ambient temperature, as otherwise full cooling would have to be buffered by almost full heating resulting in very inefficient system operation and increasing the probability of control point hunting. Switching from high to low cooling rate will produce a slight control point offset (Fig. 3) but this can be easily counteracted by adjustment of the set potentiometer.

Materials of construction are either plastic, fiberglass, epoxy-coated steel, or stainless steel. Thus, by substituting titanium for stainless steel in the cooler-heater, the system is suitable for use in either freshwater or saltwater installations.

SCOTT, K. R. 1971. Monitoring of fish tank oxygen concentration using a digital recorder. J. Fish. Res. Bd. Canada 28: 1196–1197.

SCOTT, K. R., AND D. C. GILLESPIE. 1972. A compact recirculation unit for the rearing and maintenance of fish. J. Fish. Res. Bd. Canada 29: 1071–1074.

The First Record of *Anguilla rostrata* From Alberta

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Department of Lands and Forests, Lethbridge, Alta.

RADFORD, D. S. 1972. The first record of *Anguilla rostrata* from Alberta. J. Fish. Res. Bd. Canada 29: 1084.

The first record of an American eel (*Anguilla rostrata*) is reported for Alberta. The specimen was collected in the South Saskatchewan River and probably originated from elvers stocked in Lac Pelletier in Saskatchewan in 1953.

RADFORD, D. S. 1972. The first record of *Anguilla rostrata* from Alberta. J. Fish. Res. Bd. Canada 29: 1084.

Il s'agit de la première mention d'une anguille d'Amérique (*Anguilla rostrata*) en Alberta. Le spécimen a été capturé dans la rivière Saskatchewan, et provenait probablement d'un ensemencement de civelles dans le lac Pelletier, en Saskatchewan, en 1953.

Received February 4, 1972

ON May 29, 1971, an American eel (*Anguilla rostrata*) was taken by an angler (S. Stevens of Blindloss, Alberta) at Sandy Point Bridge (50°45′N, 110°02′W) in the South Saskatchewan River. The length and weight of the specimen was 940 mm and 1420 g, respectively. Study of the otolith indicated that the eel was 22–24 years of age (C. B. Lane personal communication).

The species has not previously been reported for Alberta (Paetz and Nelson 1970) and probably originated from elvers stocked in Lac Pelletier in Saskatchewan. The species is indigenous to the Atlantic watershed in Canada (Nfld., Lab., N.S., P.E.I., N.B., Que., Ont.) according to Scott and Crossman (1969).

The Saskatchewan Department of Natural Resources initiated research on the stocking of American eels in 1953, when "a considerable number of elvers were planted in Lac Pelletier" (F. M. Atton personal communication). Atton mentioned that there have been a number of returns, ours being the latest. Lac Pelletier is located in southwest Saskatchewan (50°00′N, 107°56′W). Pelletier Creek drains Lac Pelletier and this stream flows into Swift current Creek, which enters the South Saskatchewan River. The point of capture of the eel in Alberta is about 310 km from Lac Pelletier.

PAETZ, M. J., AND J. S. NELSON. 1970. The fishes of Alberta. The Queens Printer, Edmonton, Alta. 282 p.

SCOTT, W. B., AND E. J. CROSSMAN. 1969. Checklist of Canadian freshwater fishes with keys for identification. Life Sciences Miscellaneous Publications. Royal Ontario Museum. 104 p.

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Dimethyl Sulfide as an Odor Component in Nova Scotia Fall Mackerel

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ACKMAN, R. G., J. HINGLEY, AND K. T. MACKAY. 1972. Dimethyl sulfide as an odor component in Nova Scotia fall mackerel. J. Fish. Res. Bd. Canada 29: 1085–1088.

A strong petroleum refinery odor in mackerel taken in late November 1971, near Halifax and on the outer edge of the Emerald Bank, has been identified as harmless dimethyl sulfide. It has been shown to originate from stomach contents and is specifically associated with the pteropod *Spiratella retroversa*. The dimethyl sulfide was not accompanied by any very large deposition in the fish of the known precursor of algal origin, dimethyl-β-propiothetin. Petroleum product pollution was not involved.

ACKMAN, R. G., J. HINGLEY, AND K. T. MACKAY. 1972. Dimethyl sulfide as an odor component in Nova Scotia fall mackerel. J. Fish. Res. Bd. Canada 29: 1085–1088.

L'agent responsable d'une forte odeur de raffinerie de pétrole chez des maquereaux capturés en fin de novembre 1971, près de Halifax et sur l'accore extérieur du banc Emeraude, a été identifié comme étant l'inoffensif diméthyl-sulfure. Il provenait du contenu stomacal et est spécifiquement associé au ptéropode *Spiratella retroversa*. Le diméthyl-sulfure n'est pas accompagné d'un très grand dépôt, dans le poisson, du précurseur notoire d'origine algale, le diméthyl-β-propriothétine.

Received January 17, 1972

THE Atlantic mackerel (*Scomber scombrus*) is esteemed as a food fish in coastal areas where it can be obtained fresh. In 1969 approximately 10 million lb out of an Atlantic provinces catch of 30 million lb were probably consumed fresh, with a smaller proportion being preserved by canning, freezing, pickling, or salting. The rapid development of rancidity during fresh or frozen storage has precluded major exploitation of this species as a food fish.

A strong petroleum refinery odor was observed in mackerel caught off Eastern Passage, near Halifax, N.S., in November 1971. Owing to the proximity of two oil refineries and general industrial activity in the Halifax area, contamination by petroleum products was thought possible because marine fish had previously been reported to be susceptible to such taints (Shipton et al. 1970; Vale et al. 1970; Deshimaru 1971a, b).

The odor in question has been identified in both Eastern Passage mackerel and those obtained from well offshore on the Emerald Bank as dimethyl sulfide (DMS). This is probably a normal trace component of odoriferous volatiles in fish (McLay 1967; Wong et al. 1967) but is more obvious as a shellfish odor and flavor component (Ackman and Hingley 1968). It is a frequent problem in fisheries in more northerly waters (Sipos and Ackman 1964; Ackman et al. 1967; see additional references cited by Ackman and Hingley 1968). The accumulation has usually been associated with a pteropod forming part of the diet.

Experimental — Mackerel taken by gillnet near Eastern Passage, off Halifax, N.S., were observed, at the Halifax Laboratory on November 22, 1971, to have a strong petroleum refinery odor, thought by an observer to be DMS. Fish were caught on the night of November 22–23, 1971, delivered to the Laboratory on November 23, put in plastic bags, and immediately frozen at –40 C. When the bags containing the frozen fish were examined without thawing on November 24, a pronounced odor was again immediately apparent and was identified as DMS from olfactory evidence by two of the authors with experience with this chemical. Four fish taken at random were thawed and the stomachs removed for determination of total DMS and of its precursor compound, dimethyl-β-propiothetin (DMPT) of algal origin. The eviscerated bodies of two of these fish were refrozen overnight. On November 26, sections from these fish cut transversely through the tail muscle behind the anus and parts of the belly flaps were also examined for DMS and DMPT. The stomach contents of six additional fish from the same lot were examined separately.

A number of mackerel were taken in two hauls of a bottom trawl on November 24, 1971, on the outer edge of Emerald Bank (43°30′N, 62°30′W). The fish were frozen on board and seven were thawed in the Halifax Laboratory on December 13 for examination of stomach contents and determinations of DMS and DMPT. To reduce loss of the fugitive DMS, the stomachs and contents were not weighed separately, but from known weights of stomach proper for comparable sized fish it has been possible to estimate stomach content weights.

A Varian Aerograph Hi-Fy gas chromatograph was used in this study. The column was of stainless steel tubing, 6 ft long × $\frac{1}{8}$ inch O.P., packed with 100–120 mesh Gas-Chrom Q coated with 5% SE-30. The oven was held at 50 C and helium carrier gas was passed through at 5 psig. For reference, 1 ml of a solution containing 3.4×10^{-5} g DMPT (as the hydrochloride) in 6N HCl:H_2O::1:5 was placed in a 4-oz glass bottle which was then stoppered with a rubber serum-type seal. Gas-tight syringes (Teflon-tipped plunger, Hamilton Cat. No. 1001-LT fitted with a standard Luer-Lok 24 gauge × 2-inch hypodermic needle, or No. 1750-LTN with sealed-in needle) were used to inject 0.5 ml of air and then withdraw 0.5 ml of gas from the bottle head space. After establishment of the level of gas chromatographic response to this blank, 2 ml of a 7.5 N solution of KOH in distilled water was injected through the septum. After 10 min, with occasional gentle swirling, the head space gas was assayed for DMS as described above. Standard samples of 0.5 ml gave a peak 6 cm in height on the 12-inch chart of a 1-mv recorder at Hi-Fy range 0.1 and attenuation 32X. The peak for a typical blank was 0–1 mm high at attenuation 4X, depending mostly on purity of laboratory air. As dissection of fish progressively contaminated the environment the air blank increased to as much as 5–7 mm.

Mackerel stomachs were blended for 1 min with 30 ml of water, 1 ml of 6N HCl, and about 5 g of ice in a 200-ml polyethylene container attached to a standard Waring Blendor. The container was sealed throughout with thin polyethylene film held in place with rubber bands. The head space (about equal to the head space in the reference bottle) was assayed for DMS through the polyethylene film as described above (omitting the air injection) at various times up to 1 hr, after which 3 ml of 3.5 N KOH was injected through the polyethylene film. The container contents were blended for a minimum of 15 sec, intermittently for up to 45 sec for muscle with skin attached, and the head space assayed for DMS at various times over 1 hr with one or two brief reblendings for the muscle samples. This reblending was necessary as the blended muscle samples tended to form a gel. DMPT was calculated (as the hydrochloride) from the increase in DMS. Results are given for both compounds in Tables 1 and 2.

Results and discussion — The stomach of Eastern Passage fish no. 2 (Table 1) was noted as very full. The other three fish from this lot of four, which were examined for DMS and DMPT, had lesser amounts of stomach contents (about 6 g) which were similar to those recorded for the six additional fish examined from Eastern Passage. These fish had fork lengths, live weights, and vacuum-filtered stomach contents ranging from 335 to 400 mm, 425 to 700 g, and 3.5 to 9.29 g, respectively. Stomachs contained 99% (by volume) of the pteropod *Spiratella* (*Limacina*) *retroversa*, accompanied by traces of copepods, chaetognaths, decapods, amphipods, fish eggs, and plant material. Emerald Bank fish had less food in their stomachs and a more varied diet, four out of seven containing a substantial proportion of euphausiids, and two of copepods, copepods being the dominant content in fish no. 7 (Table 2).

The levels of DMPT for stomachs and contents (Tables 1 and 2) apparently depend on total food and on the pteropod content of the food. The highest values (0.002–0.008 mg/g stomach and contents) for DMPT are about the same as those found for stomach contents from Labrador cod (Ackman et al. 1967), or Pacific chum salmon (Motohiro 1962), although these contained the closely related pteropod *Spiratella* (*Limacina*) *helicina*. Storage, even frozen, would decrease the thetin (compare Ackman et al. 1966a). One of these effects, size of fish, the food organisms, the feeding period of the mackerel

TABLE 1. Levels of dimethyl sulfide (DMS) and dimethyl-β-propiothetin (DMPT, reported as hydrochloride) in Eastern Passage mackerel stomachs and muscle.

	Tissue and weight (*g*)			DMS (*mg/g*)			DMPT (*mg/g*)		
Fish	Stomach	Tail muscle	Belly flap	Stomach	Tail muscle	Belly flap	Stomach	Tail muscle	Belly flap
1	22	16	22	0.002	0.0002	0.0002	0.002	0.0001	0.0004
2	32	22	22	0.017	0.0003	0.0002	0.008	0.0002	0.0003
3	29	–	–	0.0008	–	–	0.0007	–	–
4	37	–	–	0.0001	–	–	0.0001	–	–

TABLE 2. Levels of dimethyl sulfide (DMS) and dimethyl-β-propiothetin (DMPT, reported as hydrochloride) in Emerald Bank mackerel stomachs and contents.

	Stomach data					Fish data	
Fish	Weight (*g*)	Approx.[a] food wt (*g*)	DMS (*mg/g*)	DMPT (*mg/g*)	Observed stomach contents	Fork length (*mm*)	Weight (*g*)
5	9.0	5.8	0.0009	0.0011	Pteropods only, nearly full	283	242.4
6	6.0	4.0	0.0003	0.0003	Some pteropods, some euphausiids	250	141.0
7	6.1	3.1	0.0001	0.0002	Mostly copepods, a few pteropods and euphausiids	302	302.0
8	7.2	2.6	0.0002	0.0002	A few pteropods, some euphausiids	330	378.0
9	4.8	1.8	0.0001	0.0001	A few pteropods, some euphausiids	274	180.8
10	5.8	0.8	0.0001	0.0001	No pteropods, little else	352	509.7
11	3.0	0	0.0009	0.0007	Mostly pteropods, some copepods	295	257.8

[a] An approximate correction of stomach minus estimated wall weight was applied to obtain approximate food weight.

before capture, or the algae available to the pteropods, could account for the apparently lesser levels of DMPT found in the Emerald Bank fish as compared to the Eastern Passage fish. The latter results would be higher still if assayed for contents only.

The muscle samples showed relatively little DMPT. It could be measured in the pooled belly flaps of the Emerald Bank fish, but only at a level of about 0.00005 mg/g tissue. An accumulation of DMPT in fish muscle is presumed to depend on a steady high intake (Ackman et al. 1966a). These results agree with the stomach explorations and indicate that the mackerel acquired all of their DMPT locally from *S. retroversa* and not in their summer feeding grounds in the Gulf of St. Lawrence. The usual source of accumulation from algae in spring and summer off Labrador and Northern Newfoundland is through the pteropod *S. helicina* (Sipos and Ackman 1964; Ackman et al. 1966a, 1967) but we have no details from a reported pteropod occurrence on the North Shore of the Gulf of St. Lawrence which could be *S. retroversa*.

An abundance of pteropods are observed annually in late fall in waters off Nova Scotia (R. J. Conover personal communication). The phytoplankter and zooplankter populations are reasonably homogeneous following the fall mixing, and examination of a water sample from St. Margaret's Bay (December 15, 1971), indicated that 90% of the phytoplankters were comprised of two species of the genus *Ceratium*. The remaining 10% was almost exclusively *Halosphaera sp.* (non-motile phase). These are potentially plentiful sources of DMPT and hence of DMS. A dinoflagellate, *Amphidinium carteri*, has been shown to be rich in DMPT (Ackman et al. 1966b), while *Halosphaera* belongs to the Prasinophyceae, where 12 out of 13 species examined contained DMPT (Craigie et al. 1967). Owing to the large size of the *Halosphaera* in this stage, and the large effective cross-section of the *Ceratium* species, it is problematical if these are eaten intact by pteropods. The relative absence of smaller phytoplankters indicates that the latter are being grazed down by the pteropods, but could also be sources of DMPT.

Plant material in the stomach contents of Eastern Passage fish were not identified, but among other contemporary sources the fall decay of eelgrass (*Zostera marina*) in estuaries and tidal inlets in this area is also known to yield DMS (Ackman and Paradis unpublished data).

The DMS from the stomach should circulate through the whole body of the fish. Since there was no apparent concentration effect in the belly flaps (Table 1), which are exceptionally rich in fat (Ackman and Eaton 1972), a very suitable solvent for retention of DMS, it does not appear that the local muscle levels are influenced by postmortem diffusion from the stomach. Belly flaps from the Emerald Bank fish contained about 0.00003 mg/g DMS.

A sample of air at −30 C was withdrawn from within a polyethylene bag in which were several mackerel from Eastern Passage which had been left overnight undisturbed and at this temperature. It was calculated that this air contained approximately 2×10^{-8} g/ml DMS. The act of opening the freezer door (an upright domestic model) liberated enough DMS to give a significant increase in the gas chromatographic background for DMS in air samples taken in another room some distance away. It is thus possible that these mackerel could on organoleptic grounds be judged unacceptable for consumption themselves, even if in a frozen condition, and could also influence judgements as to the acceptability of other fishery products stored or displayed in their vicinity. Potentially, the preexisting DMS could be concentrated in the head space of cans although the DMPT present probably is not enough to yield much additional DMS as described by Motohiro (1962) for canned salmon. The DMS is, however, harmless and is driven off on cooking.

The proximity of oil refineries is known to result in a superficially similar odor/flavor problem in fish from pollution with certain hydrocarbons (Shipton et al. 1970; Vale et al. 1970). Our results comparing fish from Eastern Passage, the site of two oil refineries, with fish from Emerald Bank indicate that the petroleum refinery odor in these fish is primarily a natural phenomenon.

Acknowledgments — K. T. MacKay was supported at Dalhousie University by a Fisheries Research Board of Canada scholarship. We thank M. Paranjape for identifying the pteropods, J. McLachlan for identifying the phytoplankters, and R. J. Conover for helpful discussion.

Ackman, R. G., and J. Dale. 1965. A reactor technique for the determination by gas–liquid chromatography of dimethyl-β-propiothetin in fish tissue and marine organisms. J. Fish. Res. Bd. Canada 22: 875–883.

Ackman, R. G., J. Dale, and J. Hingley. 1966a. Deposition of dimethyl-β- propiothetin in Atlantic cod during feeding experiments. J. Fish. Res. Bd. Canada 23: 487–497.

Ackman, R. G., and C. A. Eaton. 1972. Mackerel lipids and fatty acids. Can. Inst. Food Technol. J. 4: 169–174.

Ackman, R. G., and H. J. Hingley. 1968. The occurrence and retention of dimethyl-β-propiothetin in some filter-feeding organisms. J. Fish. Res. Bd. Canada 25: 267–284.

Ackman, R. G., J. Hingley, and A. W. May. 1967. Dimethyl-β-propiothetin and dimethyl sulphide in Labrador cod. J. Fish. Res. Bd. Canada 24: 457– 461.

Ackman, R. G., C. S. Tocher, and J. McLachlan. 1966b. Occurrence ot dimethyl-β-propiothetin in marine phytoplankton. J. Fish. Res. Bd. Canada 23: 357–364.

Craigie, J. S., J. McLachlan, R. G. Ackman, and C. S. Tocher. 1967. Photosynthesis in algae. III. Distribution of soluble carbohydrates and dimethyl-β-propiothetin in marine unicellular Chlorophyceae and Prasinophyceae. Can. J. Bot. 45: 1327–1334.

Deshimaru, O. 1971a. Studies on the pollution of fish meat by mineral oils. I. Deposition of crude oil in fish meat and its detection. Bull. Jap. Soc. Sci. Fish. 37: 297–301.

1971b. Studies on the pollution of fish meat by mineral oils. II. Injury and pollution of fish due to oil dispensers. Bull. Jap. Soc. Sci. Fish. 37: 302–306.

McLay, R. 1967. Chemical studies on the herring (*Clupea harengus*). XI. Quantitative estimation of volatile sulphur compounds produced during cooking of herring. J. Sci. Food Agr. 18: 605–607.

Motohiro, T. 1962. Studies on the petroleum odour in canned chum salmon. Mem. Fac. Fish. Hokkaido Univ. 10: 1–65.

Shipton, J., J. H. Last, K. E. Murray, and G. L. Vale. 1970. Studies on a kerosene-like taint in mullet (*Mugil cephalus*) II. — Chemical nature of the volatile constituents. J. Sci. Food Agric. 21: 433–436.

Sipos, J. C., and R. G. Ackman. 1964. Association of dimethyl sulphide with the "blackberry" problem in cod from the Labrador area. J. Fish. Res. Bd. Canada 21: 423–425.

Wong, N. P., J. N. Damico, and H. Salwin. 1967. Investigation of volatile compounds in cod fish by gas chromatography and mass spectrometry. J. Ass. Offic. Anal. Chem. 50: 8–15.

Vale, G. L., G. S. Sidhu, W. A. Montgomery, and A. R. Johnson. 1970. Studies on a kerosene-like taint in mullet (*Mugil cephalus*) I. — General nature of the taint. J. Sci. Food Agric. 21: 429–432.

Subcutaneous Hemorrhage in Captive Sablefish (*Anoplopoma fimbria*): A Possible Link to Mortality

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THORSON, K. N. 1972. Subcutaneous hemorrhage in captive sablefish (*Anoplopoma fimbria*): a possible link to mortality. J. Fish. Res. Bd. Canada 29: 1089–1090.

During the spring of 1971 two groups of sablefish (*Anoplopoma fimbria*) were captured by pot fishing gear off the Washington coast. Within three days subcutaneous hemorrhages occurred in both groups and the more extensively hemorrhaged fish soon died. It appeared that the hemorrhages were a delayed reaction to injury sustained at capture. Impact against the pot walls or embolism arising from rapid decompression are suggested as possible causes.

THORSON, K. N. 1972. Subcutaneous hemorrhage in captive sablefish (*Anoplopoma fimbria*): a possible link to mortality. J. Fish. Res. Bd. Canada 29: 1089–1090.

Au printemps 1971, deux groupes de morues charbonnières (*Anoplopoma fimbria*) ont été capturées dans des casiers au large de l'Etat de Washington. En moins de trois jours, des hémorragies sous-cutanées se sont produites chez les deux groupes, et les poissons les plus sérieusement affectés moururent rapidement. L'hémorragie semble être une réaction différée à des lésions subies lors de la capture. L'auteur suggère les chocs contre la paroi du casier, ou une embolie résultant de la décompression rapide, comme causes possibles de l'hémorragie.

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DURING spring of 1971 I obtained two groups of live sablefish (*Anoplopoma fimbria*) for use in tagging research. Both groups were captured off the Washington coast using pot gear fished as described by Hipkins and Beardsley (MS 1970). They were both retained in salmon tierces for 24 hr during transport to shore. Hemorrhage was first detected after the fish had been brought ashore.

The first group, comprised of 45 sablefish, was captured at depths ranging from 200–310 fath. This group was transferred into an 8 × 16 × 14-ft deep floating pen. During feeding, extensive hemorrhages were observed on some fish in this group. The incidence was not recorded, but none of the obviously hemorrhaged fish survived over 1 month.

A second group of 23 sablefish was taken from 150 fath in June 1971. No hemorrhage was evident when they were transferred into a 1200 gal fiberglass and plywood test tank where they were retained. On the third day of captivity hemorrhage was first noted. The opportunity for close examination came when 18 fish were anesthetized and tagged. While in the tagging cradle, most fish were observed to have minute blood spots effused into the subcutaneous tissue on the undersides, in the fin tissues, and, in some instances, in the eyes. Hemorrhaging was not due to tagging, because five of the 23 sablefish were neither anesthetized nor tagged, but by the end of the week all fish had hemorrhaged to some degree. These fish were observed closely only when it was necessary to determine tag numbers of individual fish used in tests, or after their death, or both. At these times the extent of hemorrhage was determined. The various areas in which hemorrhage occurred is indicated by the shading in the sketch of sablefish in Fig. 1.

One of the reasons the fish were obtained was to observe their reaction to a polarized electric current. Often the fish were in the test area when the equipment was set up, so handling injury was minimal. Records were kept of the fish tested and though several specimens were used more than once some were not used at all. Among the fish tested, several were observed to undergo tetanic muscular contraction at higher voltage levels. The latter died within a few days. The tests, therefore, appear to be a major factor in the death of these fish but not a cause of the hemorrhage.

Table 1 indicates which fish were tagged or tested, where hemorrhages occurred, and the number of days each fish survived in captivity.

It is not the intent of Table 1 to imply a mortality schedule for hemorrhaged fish. Of the first 16 to die, however, half the fish (eight) had not been subjected to electrical tests and two were neither tagged nor tested. This indicates that prior injury was the prime

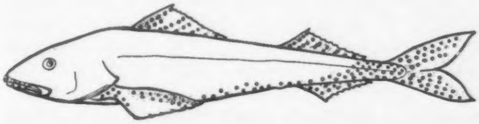

FIG. 1. Areas where hemorrhages occurred in sablefish, exaggerated by heavy stipple.

TABLE 1. Size, extent of hemorrhage, and survival for a group of 23 sablefish (*Anoplopoma fimbria*) subjected to different treatments ("x" indicates affirmative).

Fork length (*cm*)	Tagged	Tested in electric current	Extent of hemorrhage					Survival days in captivity
			Ventral[a]	Maxillary[b]	Fins[c]	Lateral[d]	Eye[e]	
51.0	x	x	x	x		x		8
53.5	x		x	x	x		x	
54.0	x	x	x	x				
48.5	x		x	x	x	x	x	
51.5	x	x	x	x				
50.0	x		x	x	x	x		
49.0	x	x	x					
47.5			x	x	x	x	x	
54.0	x		x	x	x			9
48.0	x		x	x	x			
46.5	x		x	x	x	x		
45.5	x	x	x		x			
47.0	x	x	x	x	x			
45.5		x	x	x				
70.5	x	x	x		x	x		
53.0			x	x				
50.5	x	x	x					10
55.0	x	x	x	x	x			
53.5	x	x	x	x				
56.5		x	x	x				11
56.0		x	x	x				
54.0	x	x	x	x				14
43.5	x	x	x	x				

[a] Irregular spotting of blood on undersides.

[b] Blood spots over entire maxillary.

[c] Blood spots in the membranes of one or more fins.

[d] Blood spots cover caudal peduncle and fin.

[e] Blood usually massed as a clot near pupil.

cause of death among the untested half. Upon final examination, hemorrhage among these eight fish was more severe than in fish used in the tests. Presumably, those fish that did not have extensive hemorrhages would have survived longer had they not been used in the electric tests. I believe the hemorrhages are symptomatic of injury sustained at capture rather than during subsequent handling. Conceivably, those injuries could occur from impact against the pot during the rapid ascent, or from the formation of gas emboli which result in aneurysms that later rupture. Of the two, the latter has far more serious implications for research on sablefish taken in deep water.

Despite the fact that scientists who have captured sablefish at sea generally consider them a durable fish, reports of tagging studies in widely scattered areas indicate low recovery rates: 0.22%, (Edson 1954), 0.56% (Novikov 1968), and 1.52–3.16% (Holmberg and Jones 1954). These figures to some degree reflect the intensity of the fisheries on the populations of sablefish tagged. However, the fact remains that only a small percentage of fish were recovered from the many thousands that were tagged, despite several potential years of susceptibility to the fisheries.

EDSON, Q. A. 1954. Preliminary report on the Alaska sablefish fishery. Pac. Mar. Fish. Comm. Bull. 3: 73–85.

HIPKINS, F. W., AND A. J. BEARDSLEY. MS 1970. Development of a pot system for harvesting black cod (*Anoplopoma fimbria*): a progress report. Nat. Oceanic Atmos. Admin., Nat. Mar. Fish. Serv., Explor. Fish. Gear Res. Base, Seattle, Wash. 31 p.

HOLMBERG, E. K., AND W. G. JONES. 1954. Results of sablefish tagging experiments in Washington, Oregon and California. Pac. Mar. Fish. Comm. Bull. 3: 103–119.

NOVIKOV, N. P. 1968. Tagging of the coalfish (*Anoplopoma fimbria* Pall.) in the Bering Sea and on the Pacific coast of Kamchatka. Vop. Ikhtiol. 8: 955–957. (Transl. from Russian in Probl. Ichthyol. 8: 762–764, issued by Amer. Fish. Soc.)

Downstream Movements of White Sucker, *Catostomus commersoni*, Fry in a Brown-Water Stream of Alberta

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CLIFFORD, H. F. 1972. Downstream movements of white sucker, *Catostomus commersoni*, fry in a brown-water stream of Alberta. J. Fish. Res. Bd. Canada 29: 1091–1093.

In a brown-water stream of Alberta, white sucker (*Catostomus commersonii*) fry moved downstream almost entirely at night. During June and July when the fry were moving downstream, their nocturnal "drift" pattern was more pronounced than that of any of the drifting invertebrates; and at this time their total biomass crossing a width transect per 24 hr exceeded the combined total biomass of the drifting invertebrate taxa. As the fry became larger, many more moved downstream near the surface of the water than near the stream's substrate.

CLIFFORD, H. F. 1972. Downstream movements of white sucker, *Catostomus commersoni*, fry in a brown-water stream of Alberta. J. Fish. Res. Bd. Canada 29: 1091–1093.

Dans un cours d'eau de couleur brune de l'Alberta, les alevins de catostomes noirs communs (*Catostomus commersonii*) descendent le courant presque entièrement la nuit. Lors de la descente, en juin et juillet, la "dérive" nocturne des alevins est plus prononcée que celle de tout autre invertébré dérivant. A cette époque, la biomasse totale des alevins qui traversent en 24 heures une coupe transversale du cours d'eau dépasse celle de tous les taxa d'invertébrés combinés. A mesure qu'ils grandissent, les alevins ont tendance à descendre le cours d'eau près de la surface plutôt que près du fond.

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THE Bigoray River, a small brown-water stream of west central Alberta (53°24′ N, 115°07′ W), supports few resident white suckers. There is a spawning migration of adult suckers into the Bigoray River from a larger stream, the Pembina River, shortly after the ice goes out in the spring. After spawning the adult suckers move downstream to the Pembina River and, in about a week, they are followed by the first fry of the new generation. A 1-year drift study of invertebrates in the brown-water stream (H. F. Clifford unpublished data) afforded the opportunity to study the fry's downstream movement in some detail.

Materials and methods — Fry were caught in driftnets each having a mouth aperture of 9 × 9 cm and a pore size of 320 microns. Two nets were attached to a pair of steel rods; the lower net was positioned so that its lower edge was about 3 cm above the substrate; the upper net filtered the surface water to a depth of 5 cm. Total volume of water filtered by each net during each sampling interval was determined by measuring water velocity at the mouth of each net with a direct reading current meter. Seven samples of 1-hr duration were taken at evenly spaced intervals (i.e. 0800, 1200.....0800) during the 24-hr sampling periods. At the sampling site the stream seldom has a discharge of over 1 m^3/sec. The nets were located in mid-stream, in a riffle area that was about 4 m wide in June and July 1970.

Results and discussion — In 1970, fry moved downstream during June and July. The downstream movements occurred almost entirely at night, with a pronounced peak at 2400 for each sampling date (Fig. 1). The fry's nocturnal "drift" pattern was much more pronounced than that of any invertebrate exhibiting a night-active drift pattern in the brown-water stream. For example the ephemeropteran *Baetis* is known from various regions of the world, e.g. Japan (Tanaka 1960), England (Elliott 1967), to have a pronounced night-active drift pattern. For the 1-year study period in the Bigoray River, *Baetis* had a night–day drift ratio of 8, whereas the white sucker fry's night–day drift ratio was 49. This was the highest value of any of the drifting animals in the Bigoray River. By knowing the discharge of the stream, a crude estimation could be made of the total biomass of fry moving past a width transect for each 24-hr period (Table 1). The fry caught in the nets were measured to the nearest millimeter and then their biomass calculated

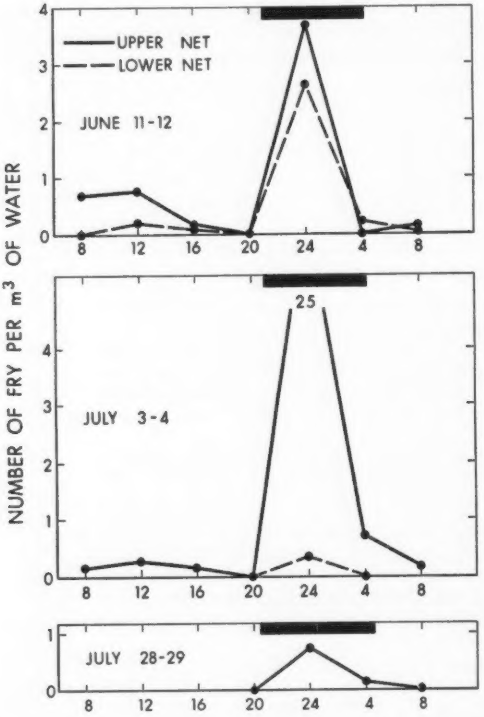

FIG. 1. Number of white sucker fry per cubic meter of water caught in the lower and upper driftnets, June and July 1970. The black bars indicate the periods between sunset and sunrise.

TABLE 1. Calculated total daily biomass (g/24 hr) of white sucker fry and the abundant invertebrate taxa moving past a width transect in the Bigoray River for three sampling periods in June and July, 1970.

	White sucker fry (*g*)	Invertebrates (*g*)
June 11–12	176	99
July 3–4	3077	153
July 28–29	346	114

by using the length–weight formula of Bigoray River white suckers as furnished by W. A. Bond (unpublished data). When one considers the entire period of downstream movement of white sucker fry in the Bigoray River, usually most of June and all of July, it is evident that these movements represent a substantial transport of organic matter downstream. During June and July, the amount of "drift" biomass represented by white sucker fry was much greater than the combined total biomass of the important drifting invertebrate taxa. The taxa of Table 1 collectively made up about 85% of the total numbers of drifting invertebrates for each of the three dates. For the midnight sample of July 3, it was estimated that 0.46 g of fry was moving downstream per cubic meter of water.

The fry do not move downstream randomly distributed throughout the water column. More fry per unit volume of water were caught in the upper net than in the lower net (Fig. 1). After log transformation of the data, the paired variate *t*-test indicated that there were significantly ($P < 0.05$) larger numbers of fry in the upper net. In contrast, for the various immature aquatic insect species there were no significant differences in numbers between the upper and lower nets (H. F. Clifford unpublished data).

Geen et al. (1966) have also reported white sucker fry moving downstream mainly at night. It is not known whether the fry actively swim downstream or are passively transported in the water downstream. Hoar (1953) reports that chum salmon (*Oncorhynchus keta*) fry maintain their position in strong current during the day, but their rheotactic response fails when light intensity falls, and hence they pass downstream at night. Northcote (1962), using an infrared apparatus, found that rainbow trout fry, which also move downstream at night, were mainly moving downstream with their heads pointing downstream. In the Bigoray River, white sucker fry were found in significantly larger numbers in the upper net. However, in June when the fry are small (average size was 12 mm) and slender, considerable numbers were found in the lower net (Fig. 1). In July when the fry were larger (average size was 17 mm on 3 July and 23 mm on 28 July) and considerably more robust, they were never caught in the lower driftnet except for one sampling interval. If one assumes that the passive transport of fry downstream would result in a more or less random distribution of fry throughout the water column (as was found for the immature aquatic insects), it is probable that some of the very young white sucker fry are passively transported downstream, but very soon, as they grow, the fry actively move downstream.

Acknowledgments — I am indebted to Miss J. Killoran and Mr M. Lee for assistance in various aspects of the study. The study was supported by a grant from the National Research Council of Canada.

ELLIOTT, J. M. 1967. Invertebrate drift in a Dartmoor stream. Arch. Hydrobiol. 63: 202–237.

GEEN, G. H., T. G. NORTHCOTE, G. F. HARTMAN, AND C. C. LINDSEY. 1966. Life histories of two species of Catostomid fishes in Sixteenmile Lake, British Columbia, with particular reference to inlet stream spawning. J. Fish. Res. Bd. Canada 23: 1761–1788.

HOAR, W. S. 1953. Control and timing of fish migration. Biol. Rev. (Cambridge) 28: 437–452.

NORTHCOTE, T. G. 1962. Migratory behaviour of juvenile rainbow trout, *Salmo gairdneri*, in outlet and inlet streams of Loon Lake, British Columbia. J. Fish. Res. Bd. Canada 19: 201–270.

TANAKA, H. 1960. On the daily change of drifting of benthic animals in streams, especially on the types of daily change observed in taxonomic groups of insects. Bull. Freshwater Fish. Res. Lab. Tokyo 9: 13–24.

First Records of *Bathysaurus mollis* (Pisces: Bathysauridae) From the Northeast Pacific Ocean

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STEIN, D., AND J. BUTLER. 1972. First records of *Bathysaurus mollis* (Pisces: Bathysauridae) from the northeast Pacific Ocean. J. Fish. Res. Bd. Canada 29: 1093–1094.

Three male *Bathysaurus mollis*, standard lengths 678, 458, and 440 mm, were captured 560 km off the coast of Oregon in 3358–3780 m. These are the first records of this species in the northeast Pacific. The 678-mm specimen, the largest reported individual of the species, has irregular rather than oval orbits. Variation exists between individuals in the position of the gill tooth plates.

STEIN, D., AND J. BUTLER. 1972. First records of *Bathysaurus mollis* (Pisces: Bathysauridae) from the northeast Pacific Ocean. J. Fish. Res. Bd. Canada 29: 1093–1094.

Trois spécimens mâles de *Bathysaurus mollis*, mesurant 678, 458 et 440 mm de longueur standard, ont été capturés à 560 km au large de la côte de l'Orégon, à des profondeurs de 3358 à 3780 m. Ce sont les premières mentions de cette espèce dans le nord-est du Pacifique. Le spécimen de 678 m, un record de longueur pour l'espèce, a des orbites de forme irrégulière plutôt qu'ovale. La position des plaques dentaires branchiales varie selon les individus.

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THREE male *Bathysaurus mollis*, the first of this species recorded from the northeast Pacific, were captured with a 3-m beam trawl on Tufts Abyssal plain about 560 km off Oregon by R/V *Yaquina*. Two individuals, 678 and 458 mm SL, were captured on May 31, 1970, at 44°55.9′N, 131°25.6′W, in 3358 m. The third individual, 440 m SL, was captured on June 5, 1970, at 44°32.0′N, 134°43.6′W, in 3780 m.

These specimens were compared with all known reports of *B. mollis* (Gunther 1878; Vaillant 1888; Vaillant, in Roule 1919; Townsend and Nichols 1925; Koefoed 1927; Nybelin 1957; and Mead 1966), with which they generally agree except for the gill tooth plate counts. Mead (1966) reported 6 +15 gill tooth plates on the first gill arches of two specimens 215 and 188 mm SL. In our two largest specimens, the number of gill tooth plates on the outside first arch is 5 +14; in our smallest, 5 +16.

Only Mead (1966) has described the gill tooth plates in detail. Our specimens differ. Mead's (1966) specimens had one row of gill tooth plates located mesially on the first gill arches. In our smaller specimens, the positions of these plates are irregular; on the same arch they are paired in some places and alternate from side to side in others. In our largest specimen, the plates alternate regularly. These differences in gill tooth plate position may represent a change with increasing size and age from small individuals with a single series of tooth plates to large individuals with alternating tooth plates.

Our largest specimen (678 mm) is the largest reported for this species. It differs from all other

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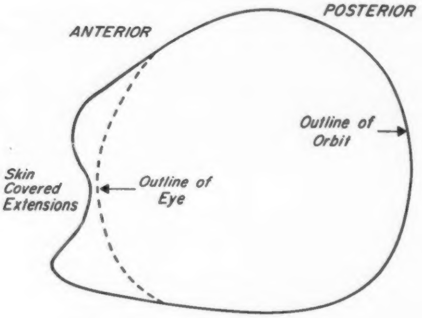

FIG. 1. Orbit of *B. mollis.*

known specimens in having very irregular (Fig. 1) rather than oval orbits. The two anterior extensions of the orbit are skin covered and are not immediately apparent. The larger of these extends forward from the anterior ventral quadrant, the smaller from the anterior dorsal quadrant.

In previous descriptions, *B. mollis* has been described as white (Townsend and Nichols 1925) or white with black bars (Mead 1966). The color of our fresh specimens was white with a black patch of skin between the pectoral fins extending forward to the isthmus. The few scales remaining were in the same location, suggesting that skin and scales are easily lost, and that the true coloration is black or dark brown, as it is in another member of the genus, *B. agassizii*, which is dark brown.

Bathysaurus mollis has been recorded throughout the Pacific Ocean: off Baja California in 3220 m, off Japan in 3429 m, in the South Pacific in 4361 m (Mead 1966), and now in the northeast Pacific in 3358–3780 m. It is also known from the northeast Atlantic in 2615–4360 m, and the Gulf of Mexico in 3150–4700 m (Mead 1966). The established range throughout the Pacific Ocean suggests that more sampling will show this species to be very widespread.

Acknowledgments — The authors would like to thank Mrs M. M. Dick, Museum of Comparative Zoology, Harvard University, for the loan of two *B. mollis*, and Dr W. G. Pearcy for his assistance and advice. This work was supported by AEC Contract AT (45-1)2227 Task Agreement 12, RLO-2227-T12-24.

GUNTHER, A. 1878. Deep sea fishes collected during the voyage of the "Challenger". Ann. Mag. Natur. Hist. 5: 179–187.

KOEFOED, E. 1927. Fishes from the sea-bottom. Rep. "Michael Sars" N. Atl. Deep-Sea Exped. 4: 1–148.

MEAD, G. 1966. Bathysauridae. Fishes West. N. Atl. 1: 103–113.

NYBELIN, O. 1957. Deep-sea bottom fishes. Rep. Swed. Deep-Sea Exped. 2 (Zool.) 20: 250–345.

TOWNSEND, C., AND J. NICHOLS. 1925. Deep sea fishes of the "Albatross" Lower California Expedition. Bull. Amer. Mus. Natur. Hist. 52: 1–20.

VAILLANT, L. 1888. Exp. Sci. "Travailleur" et "Talisman" poissons. Paris. 406 p.

1919. In Roule. Res. Camp. Sci. Monaco 52: 120–135.

Recent Articles on FRB Investigations Published in Other Periodicals

Until 1970, reprints of these articles had been included in an annual volume of "Studies," composed of two parts. The final binding was the 1969 Studies, Part 2, which included No. 1355. These are no longer bound and distributed. We continue, however, to number and list all articles, which henceforth may be obtained in reprint form only from the author or originating FRB establishment. The number following each title refers to the FRB establishment listed below.

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1637. Brockerhoff, H. 1971. Stereospecific analysis of triglycerides. Lipids 6: 942–956. (8)

1638. Ackman, R. G., S. N. Hooper, and J. Hingley. 1971. Monoethylenic fatty acids of a partially hydrogenated herring oil. J. Amer. Oil Chem. Soc. 48: 804–806. (8)

1639. Castell, C. H. 1971. Metal-catalyzed lipid oxidation and changes of proteins in fish. J. Amer. Oil Chem. Soc. 48: 645–649. (8)

1640. Hodder, V. M., and L. S. Parsons. 1971. Some biological features of southwest Newfoundland and northern Scotian Shelf herring stocks. ICNAF Res. Bull. 8: 67–73. (9)

1641. Hodder, V. M., and L. S. Parsons. 1971. Comparison of certain biological characteristics of herring from Magdalen Islands and southwestern Newfoundland. ICNAF Res. Bull. 8: 59–65. (9)

1642. Halliday, R. G. 1971. Recent events in the haddock fishery of the eastern Scotian Shelf. ICNAF Res. Bull. 8: 49–58. (6)

1643. Kohler, A. C. 1971. Tagging of white hake, *Urophycis tenuis* Mitchill, in the southern Gulf of St. Lawrence. ICNAF Res. Bull. 8: 21–25. (6)

1644. Parsons, L. S., and V. M. Holder. 1971. *Variations in the incidence of larval nematodes* in herring from Canadian Atlantic waters. ICNAF Res. Bull. 8: 5–14. (9)

1645. Iles, T. D. 1971. The retention inside the Bay of Fundy of herring larvae spawned off the southwest coast of Nova Scotia. ICNAF Redb. 1971 III: 93–103. (6)

1646. Schindler, D. W. 1971. Carbon, nitrogen, and phosphorus and the eutrophication of freshwater lakes. J. Phycol. 7: 321–329. (4)

1647. Ross, H. H., and W. E. Ricker. 1971. The classification, evolution, and dispersal of the winter stonefly genus *Allocapnia*. Ill. Biol. Monogr. 45: 166 p. (1)

1648. Hiltz, D. F., W. J. Dyer, S. Nowlan, and J. R. Dingle. 1972. Variation of biochemical quality indices by biological and technological factors, p. 191–195. *In* R. Kreuser [ed.] Fish inspection and quality control. Fishing News Books, London. (8)

1649. Dyer, W. J. 1972. Speed of freezing and quality of frozen fish, p. 75–81. *In* R. Kreuser [ed.] Fish inspection and quality control. Fishing News Books, London. (8)

1650. Bligh, E. G. 1972. Specific problems in the quality assessment of freshwater fish, p. 81–86. *In* R. Kreuser ed. Fish inspection and quality control. Fishing News Books, London. (8)

1651. Parsons, T. R., K. Stephens, and M. Takahasha. 1972. *The fertilization of Great Central Lake* I. Effect of primary production. Fish. Bull. 70(1): 13–23. (1)

1652. LeBrasseur, R. J., and O. D. Kennedy. 1972. The fertilization of Great Central Lake II. Zooplankton standing stock. Fish. Bull. 70(1): 25–36. (1)

1653. Barraclough, W. E., and D. Robinson. 1972. The fertilization of Great Central Lake III. Effect on juvenile sockeye salmon. Fish. Bull. 70(1): 37–48. (1)

1654. Li, M. F., and G. S. Traxler. 1972. Antiviral activiy of aqueous clam (*Mya arenaria*) extract on amphibian virus (LT-1). Can. J. Microbiol. 18: 397–402. (8)

1655. Barica, J., and F. A. J. Armstrong. 1971. Contribution by snow to the nutrient budget of some small northwest Ontario lakes. Limnol. Oceanogr. 16: 891–899. (4)

1656. Zitko, V. 1972. Absence of chlorinated dibenzodioxins and dibenzofurans from aquatic animals. Bull. Environ. Contam. Toxicol. 7: 105–110. (6)

1657. Strasdine, G. A. 1972. The role of intracellular glucan in endogenous fermentation and spore maturation in *Clostridium botulinum* type E. Can. J. Microbiol. 18: 211–217. (2)

1658. Boyce, N. P. 1971. Ezonema bicornis gen. et sp. n. (nematoda: seuratidae) from freshwater fishes of Hokkaido, Japan. J. Parasitol. 57: 1175–1179. (1)

1659. Zitko, V., O. Hutzinger, W. D. Jamieson, and P. M. K. Choi. 1972. Polychlorinated terphenyls in the environment. Bull. Environ. Contam. Toxicol. 7: 200–201. (6)

1660. Carey, F. G., J. M. Teal, J. W. Kanwisher, and K. D. Lawson. 1971. Warm-bodied fish. Amer. Zool. 11: 135–143. (6)

1661. Zitko, V. 1972. Problems in the determination of polychlorinated biphenyls. Int. J. Environ. Anal. Chem. 1: 221–231. (6)

1662. Wildish, D. J. 1972. Polychlorinated biphenyls (PCB) in sea water and their effect on reproduction of *Gammarus oceanus*. Bull. Environ. Contam. Toxicol. 7: 182–187. (6)

1663. Idler, D. R., and L. M. Safe. 1972. Separation of steryl acetates by silver ion chromatography. Steroids 19: 315–324. (8)

1664. Ackman, R. G. 1972. The analysis of fatty acids and related materials by gas-liquid chromatography, p. 167–269. *In* R. T. Holman [ed.] Progress in the chemistry of fats and other lipids. Vol. 12. Pergamon Press, New York, N. Y. (8)

1665. Idler, D. R. 1972. Some compatative aspects of corticosteroid metabolism. Excerpta Med. Int. Congr. Ser. 219: 14–28. (8)

1666. Idler, D. R., G. B. Sangalang, and M. Weisbart. 1972. Are corticosteroids present in the blood of all fish? Excerpta Med. Int. Congr. Ser. 219: 983–989. (8)

1667. MacKay, K. T. 1972. Further records of the stromateoid fish *Centrolophus niger* from the northwestern Atlantic, with comments on body proportions and behavior. Copeia 1972: 185–187. (7)

1668. Bligh, E. G. 1972. Mercury in Canadian fish. Can. Inst. Food Sci. Technol. J. 5: A6–A14. (8)

1669. Platt, T. 1972. Local phytoplankton abundance and turbulence. Deep-Sea Res. 19: 183–187. (7)

1670. Sundararaj, B. I., T. C. Anand, and E. M. Donaldson. 1972. Effects of partially purified salmon pituitary gonadotropin on ovarian maintenance, ovulation, and vitellogenesis in the hypophysectomized catfish, *Heteropneustes fossilis* (Bloch). Gen. Comp. Endocrinol. 18: 102–114. (2)

1671. Patalas, K. 1972. Primary and secondary production in a lake heated by thermal power plant. Proc. 16th Annu. Tech. Meet. Inst. Environ. Sci. Boston. p. 267–271. (4)

1672. Patalas, K. 1971. The crustacean plankton communities of lakes. Trans. Amer. Microsc. Soc. 90: 117–118. (4)

1673. Ackman, R. G. 1972. Influence of methyl substituent position on retention times in the GLC of higher monomethylbranched fatty acid esters and hydrocarbons. J. Chromatogr. Sci. 10: 243–246. (8)

1674. Addison, R. F., and R. G. Ackman. 1971. Erythrocyte lipids of Atlantic cod, *Gadus morhua*. Can. J. Biochem. 49: 873–876. (8)

Additional FRB Publications

The Fisheries Research Board of Canada also publishes a series of *Bulletins*, each on a specific topic. These are for sale by Information Canada, Ottawa, and remittances must be in advance, payable in Canadian funds to the order of the Receiver General of Canada. *Bulletins* are also available from local booksellers and Information Canada bookshops throughout Canada.

The *Annual Report* of the Board and the biennial *Review* of investigations are available free, on request. All publications may be referred to at Board establishments located at: Ottawa; Nanaimo, Vancouver, and West Vancouver, B.C.; Winnipeg, Man.; Ste. Anne de Bellevue, Que.; St. Andrews, N.B.; Halifax and Dartmouth, N.S.; and St. John's, Nfld.

L'Office des recherches sur les pêcheries du Canada publie également une série de *Bulletins*, chacun traitant sur un sujet spécifique. Les publications de l'ORP sont vendues par Information Canada à Ottawa. Les remises, payables d'avance en monnaie canadienne, doivent être établies à l'ordre du Receveur général du Canada. Les *Bulletins* sont aussi en vente chez votre libraire et dans les librairies d'Information Canada.

Vous pouvez obtenir le Rapport Annuel et la Revue biennale gratuitement. On peut consulter ces ouvrages aux établissements de l'Office situés a Ottawa (Ont.), à Nanaïmo, à Vancouver, et à Vancouver Ouest (C.-B.), à Winnipeg (Man.), à Ste-Anne-de-Bellevue (P.Q.), à St-Andrews (N.-B.), à Halifax et à Dartmouth (N.-E.), et à St-Jean (T.-N.).

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Guide to Authors

Details on typing and other items in preparing copy are given in a guide for typists. Also, a list of recommended spellings of about 100 words common in fisheries journals is available from the Office of the Editor.

Editorial Practices

Abstracts should be provided in both English and French.

The *Style Manual for Biological Journals* (2nd ed. American Institute of Biological Sciences, 2000 P St. NW., Washington, D.C.) is, with few exceptions, used as the authority in matters of form. *Webster's Third New International Dictionary* is the standard for spelling and division of words in English; *le Grand Larousse Encyclopédique*, for those in French. Exceptions are made for manuscripts that follow the *Oxford English Dictionary* entirely. Titles of periodicals are abbreviated as in the *Biological Abstracts* list. References to literature are made by the name-and-year system. Manuscript reports are included in the list of references, but are identified both there and in the text by the letters "MS" before the year. The *Journal* follows the spelling recommended in *A List of Common and Scientific Names of Fishes from the United States and Canada* (Third Edition, 1970), Special Publication No. 6 of the American Fisheries Society.

Notes are distinguished from *papers* on the basis of scope or completeness, rather than quality, of the research. They may be on problems with narrow, readily defined limits; on fishing gear or methods, or research techniques; on advances in knowledge arising as by-products of broader studies; on progress in projects that were discontinued before completion; or on preliminary findings that warrant publication before problems are resolved satisfactorily. Or they may be used to establish priority in publication. They may be organized with as much flexibility as papers except that they may have no centered headings. They should take no more than four pages in the *Journal*.

In general, *series titles* should be avoided.

ILLUSTRATIONS

Line drawings are preferably made with black india ink on white drawing or tracing paper or on coordinate paper with blue grids. All lines, symbols, letters, and numerals must be neat, and legible when the illustration is reduced to the appropriate size. Drawings should be grouped, when feasible, for economy of space. Originals must be submitted and should be less than 20 inches in the greater dimension for full-page illustrations, and proportionately smaller for those taking less than a page. Drawings must not be rolled for mailing.

Prints of photographs should be made on glossy paper with a wide range in tone. They should be cropped, squared, and mounted with rubber cement on white cardboard, with no space between those arranged in groups.

PROOFS AND REPRINTS

Galley proof is sent to the author, and he is responsible for detecting errors in printing as well as in content.

Fifty reprints, without covers, are supplied free. Additional copies needed must be ordered, on the form provided, when the galley proof is returned.

Checklist on Manuscripts

Attention to the following questions will expedite appraisal of manuscripts by referees and editors. The same questions are recommended to referees who review manuscripts for the *Journal*.

GENERAL

Is there new knowledge in the report worth publishing?
Are the findings, interpretations, and conclusions sound, and relevant to the purpose of the study?
If the manuscript is merely confirmatory, is it worth publishing?

Does the manuscript need to be rewritten before the work can be assessed?

Is the contribution placed in the proper perspective concerning the state of knowledge of the subject?

Is the manuscript too long?
Are all the tables and figures needed, and organized for economy of space?
Would any of the text be clearer if condensed?
Should some of the data be made available separately, in a manuscript report or at a data repository?
Should the manuscript be condensed as a Note?

Does the organization of the manuscript follow logically from the statement of purpose in the introduction?

Are summary statements given at the beginnings of sections and paragraphs, and are details in sections and paragraphs relevant to their topics?

Are there inconsistencies between tables or figures and the text, or within the text?

If the manuscript is from a thesis, does it retain characteristics common in these but not desirable in journals?

PARTS OF THE MANUSCRIPT

Does the *title* encompass the content of the report?

Does the *abstract* give the essentials of the new knowledge?

Has the *introduction* all the important guideposts for orienting the reader?
Is review of the literature limited to defining the problem?

Are details of *materials and methods* limited to what scientists need in understanding the design of the study and in judging adequacy of the data obtained?

Are generalizations on the *results* adequate?
Are findings distinguished from inferences from them?

Is *discussion* limited to interpretation and significance of the findings?
If there are loopholes in interpretation, are they acknowledged? Should they be overcome?
Should other interpretations be recognized?

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Guide des auteurs

Des détails sur le tapage et certains autres item sont donnés dans le "Guide pour les secrétaires d'auteurs." Aussi, une liste d'épellations recommandées d'environ 100 mots relatifs aux articles sur les pêcheries est disponible au bureau du Directeur de la publication.

Disposition générale

Les résumés doivent être fournis en anglais et en français.

Le *Style Manual for Biological Journals* (deuxième édition, publié par l'American Institute of Biological Sciences, 2000, rue *P* N.-O., Washington, D.C.), a été adopté comme guide des auteurs. Le *Third New International Dictionary* de Webster, dans le cas de l'anglais, et le *Grand Larousse Encyclopédique*, dans le cas du français, font respectivement autorité pour l'orthographe et la séparation des mots. Une exception est faite à l'égard des travaux en anglais qui se conforment entièrement à l'*Oxford English Dictionary*. Les titres de périodiques sont abrégés selon la *Biological Abstracts*. Toute référence à la littérature doit suivre le système nom-année. Les rapports manuscrits sont inclus dans la liste des références, les lettres "MS" avant l'année les identifient dans les références et dans le texte. Le *Journal* se sert des épellations recommandées dans *A List of Common and Scientific Names of Fishes from the United States and Canada* (Troisième édition, 1970), Publication spéciale No 6 de l'American Fisheries Society.

Les *notes* se distinguent des écrits d'après l'étendue de la recherche plutôt que par la qualité de la recherche. Les notes peuvent être sur des travaux de recherche de portée restreinte, susceptibles de découler d'investigations plus considérables, pour la description de techniques de recherche et de méthodes de pêche, pour l'établissement de priorités de publication, et pour faire connaître les renseignements utiles tirés d'entreprises qui ont été interrompues avant d'avoir été achevées. Si la portée de la Note le permet, elle peut être disposée comme un mémoire. D'autre part, la disposition est flexible. La longueur ne doit pas dépasser quatre pages imprimées.

En général, les mémoires en série doivent être évités.

LES ILLUSTRATIONS

Les dessins au trait doivent être exécutés à l'encre de chine sur papier à dessin blanc ou sur papier à calquer, ou sur papier à coordonnées avec quadrillage bleu. Les lignes, les symboles, les lettres et les chiffres doivent tous être propres. Ils doivent être lisibles quand ils sont réduits à la grandeur voulue pour la reproduction désirée. Les dessins doivent être groupés, si la chose est possible, de façon à utiliser tout l'espace disponible. Les originaux doivent être soumis et devraient mesurer moins de 20 pouces dans le sens le plus long pour les illustrations de pages entières, et proportionnellement plus petit pour les illustrations de moins d'une page. Les dessins doivent être postés à plat.

Les épreuves des photographies doivent être tirées sur papier glacé et accuser une gamme étendue de teintes. Elles doivent être coupées, dressées et montées, au moyen de dissolution, sur carton blanc, sans laisser d'espace entre celles qui sont disposées par groupes.

EPREUVES ET TIRES A PART

Les épreuves en placards sont adressées à l'auteur et la responsabilité de toute erreur qui peut y rester lui incombe.

Cinquante tirés à part, sans couverture, sont fournis gratuitement. L'auteur peut profiter du renvoi des épreuves en placards pour commander d'autres tirés à part.

Liste de contrôles pour manuscrits

Une attention particulière portée sur les questions suivantes facilitera l'évaluation des manuscrits par les arbitres et les rédacteurs. Les mêmes questions sont recommandées aux arbitres qui font la critique des livres pour le *Journal*.

GENERALITES

Est-ce que les connaissances nouvelles du rapport méritent d'être publiées?

Les découvertes, les interprétations et les conclusions sont-elles solides et pertinentes au but de l'étude?

Si le manuscrit est tout simplement corroboratif, mérite-t-il d'être publié?

Le manuscrit doit-il être récrit avant d'évaluer le travail?

La contribution est-elle placée dans une perspective appropriée relative à l'état des connaissances du sujet?

Le manuscrit est-il trop long?

Les tables et figures sont-elles toutes nécessaires et arrangées pour économiser le plus d'espace?

Le texte serait-il plus clair s'il était condensé?

Est-ce qu'une partie des données devrait être disponible séparément, soit dans un rapport ou dans un dépôt des données?

Le manuscrit devrait-il être condensé en une note?

Est-ce que la préparation du manuscrit suit la logique mentionnée dans l'introduction?

Y a-t-il des exposés sommaires au début de chaque section et paragraphe, et les détails de ces sections et paragraphes sont-ils pertinents aux sujets?

Y a-t-il des contradictions entre les tableaux et les figures du texte, ou dans le texte même?

Si le manuscrit est tiré d'une thèse, contient-il des caractéristiques communes à cette dernière, mais indésirables dans un journal?

PARTIES DU MANUSCRIT

Le titre renferme-t-il le contenu du rapport?

Le résumé donne-t-il l'essentiel des connaissances nouvelles?

L'introduction a-t-elle tous les points importants afin d'orienter le lecteur?

Le renvoi bibliographique se limite-t-il à la définition du problème?

Les détails du matériel et des méthodes employées sont-ils limités à un minimum pour que les scientifiques comprennent le but de l'étude et puissent porter un jugement adéquat sur les données obtenues.

Les généralisations sur les résultats sont-elles adéquates?

Les conclusions sont-elles déduites des résultats?

La discussion est-elle limitée à l'interprétation et la signification de ces découvertes?

S'il y a des échappatoires dans l'interprétation, sont-elles reconnues? Devraient-elles être maîtrisées?

Devrait-on accepter d'autres interprétations?

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Guide for Typists Preparing Copy

Read the "Guide to Authors" in the current volume of the *Journal*. When in doubt about how to type or arrange details, follow *Journal* practice.

Type the manuscript on white bond paper, not flimsy, preferably size 8.5 × 11 inches (21.5 × 28 cm). If possible, use paper with the lines numbered in the margin. Leave all margins at least 1 inch (2.5 cm) wide. Use a nylon or carbon ribbon and keep the typewriter keys clean.

Double-space all parts of the manuscript, including tables, captions for illustrations, footnotes, and the reference list. Underline only material that is to be printed in italics. Indent the first line of each paragraph in the text and of each footnote.

In titles and headings, capitalize only the first word and proper names and adjectives. For small capitals, use small letters.

Indicate all text footnotes by superscript arabic numbers. Number them consecutively throughout the manuscript, starting with those on the title page. Place each footnote immediately below the reference to it, separating it from the text by horizontal lines.

On the first page type only the title, the authors' names and affiliations, related footnotes, and the running head (Appendix A). Type the abstract on a separate page (Appendix B). Number all pages, beginning with the title page and including those for tables and captions for illustrations.

Have the author check the finished manuscript, and send two copies (the ribbon copy and a carbon copy or a photocopy) to the Office of the Editor.

TABLES

Examine the current volume of the *Journal* to see how tables are set up (Appendix C).

Note especially the following concerning *numbered tables*:

Type each table on a separate page, using paper without the lines numbered.

Number the tables with arabic numerals.

Use horizontal lines above and below the headings and below the columns, and seldom elsewhere. Never use vertical lines; leave extra spaces instead.

Indicate table footnotes by superscript small letters and type them below the table.

Place the tables after the list of references.

Where each table is first referred to, type in the margin "Table — near here."

Note that *text tables* are not numbered, they are typed with the text, they seldom need horizontal lines, and the data are arranged in as few rows as possible (Appendix C).

ILLUSTRATIONS

Send the original and two clear copies of each illustration with the manuscript. At the lower left of each figure and copy, give the author's name and the figure number. Also type each caption with its figure for identification. For photographs, type this information on a strip of paper and fasten it to the back of the print. Do not write or type on the print itself. Also, type the captions in succession on a separate page, headed "Captions for illustrations." Put this page at the end of the manuscript.

Where each figure is first referred to, type in the margin "Fig. — near here."

MATHEMATICAL EXPRESSIONS, EQUATIONS, AND FORMULAS

Leave three spaces above and below lines that have much material in superscripts or subscripts, and above and below equations and formulas. In the various expressions, place each component in its correct position (Appendix D).

Show all symbols clearly. In the margin, spell out Greek letters the first time they occur, and distinguish between the small letter l and the numeral one, and between the capital letter O and the numeral zero. Make other explanatory notes similarly.

REFERENCES

Check the text to see that all references in the list are referred to. Type the reference list, double-spaced, in the style that is used in the *Journal* (Appendix E). Names of journals are abbreviated as in the *Biological Abstracts* list, but if an abbreviation is in doubt, type the name in full.

SPELLINGS

A list of about 100 words common in fisheries journals is given in Appendix F.

APPENDICES

Appendices A to F are available on request from the Office of the Editor.

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Guide pour les secrétaires d'auteurs

Lisez le "Guide des auteurs" dans l'édition courante du *Journal.* Si vous avez des doutes sur la façon de taper ou d'arranger les détails, suivez la pratique du *Journal.*

Tapez le manuscrit sur un papier blanc et non un papier pelure, mesurant de préférence 8½ × 11 po. (21.5 × 28 cm) et laissant une marge d'au moins 1 po. (2.5 cm). Si possible, employez un papier avec des lignes numérotées dans la marge. Employez un ruban nylon ou carbone et gardez les clés du dactylo nettes.

Chaque partie du manuscrit doit être tapée à double-interligne au moins. La chose est particulièrement importante dans le cas des tableaux, légendes d'illustrations, renvois au bas de la page et listes de références bibliographiques. Evitez de souligner à moins que la matière ne soit en italique. Mettez en retrait la première ligne de chaque paragraphe du texte, ainsi que de chaque légende et renvoi.

Dans les titres et en-têtes, n'employez la majuscule que pour le premier mot, les noms propres et les adjectifs. Pour les petites majuscules, utilisez les petites lettres.

Indiquez tous les renvois au texte par des chiffres arabes en-tête. Numérotez-les consécutivement à travers le texte en commençant par ceux de la page-titre. Placez chaque renvoi immédiatement sous sa référence, le séparant du texte par des lignes horizontales.

La première page ne doit donner que le titre du sujet, le nom et l'affiliation de l'auteur ou des auteurs, et tout autre renvoi utile (Appendice A). Tapez le résumé sur une page séparée (Appendice B). Numérotez chaque page, débutant avec la page-titre.

Voyez à ce que l'auteur vérifie le manuscrit final, et soumettez la première copie et un double du travail au Directeur de la publication.

TABLEAUX

Consultez une copie du *Journal* pour savoir composer les tableaux et placer les lignes qui y entrent (Appendice C).

Portez une attention particulière à ce qui suit concernant les *tableaux numérotés.*

Tapez les tableaux sur des pages séparées, en utilisant du papier sans lignes numérotées.

Numérotez les tableaux avec des chiffres arabes.

Employez des lignes horizontales au-dessus et au-dessous des en-têtes et au-dessous des colonnes, et très rarement ailleurs. N'employez jamais de lignes verticales; de préférence, laissez de l'espace supplémentaire.

Indiquez les renvois dans les tableaux au moyen de petites lettres italiques en position supérieure et tapez-les au bas de la page.

Placez les tableaux après la liste de références.

A l'endroit où un tableau est mentionné pour la première fois, tapez dans la marge "Tableau (- - -) près d'ici."

Remarquez que les *tableaux dans le texte* ne sont pas numérotés, ils sont tapés avec le texte. Ils ont rarement besoin de lignes horizontales, et l'information est préparée de façons à prendre le moins de rangées possibles.

ILLUSTRATIONS

Joignez au manuscrit expédié le dessin original des illustrations et des photocopies en deux exemplaires.

Au bas et à gauche de chaque figure et photocopie, inscrivez le nom de l'auteur et le numéro de la figure. Aussi, tapez chaque légende avec sa figure pour fin d'identification. Pour les photographies, tapez l'information sur une lisière de papier et collez-la au dos de la photographie. N'écrivez pas et ne tapez pas sur la photographie même. Tapez ensemble sur une feuille séparée et par ordre consécutif les légendes des illustrations, et intercalez cette feuille à la suite du texte.

A l'endroit où chaque figure est mentionnée pour la première fois, tapez dans la marge "Fig. (- - -) près d'ici."

EQUATIONS, FORMULES ET EXPRESSIONS MATHEMATIQUES

Laissez trois espaces au-dessus et au-dessous des lignes qui contiennent du matériel en positions supérieures ou en positions inférieures, et au-dessus et au-dessous d'équations et de formules. Dans les différentes expressions, placez chaque composante dans sa position appropriée (Appendice D).

Indiquez les symboles clairement. Dans la marge, épelez les lettres grecques la première fois qu'elles apparaissent et faites une distinction entre la lettre "l" et le chiffre "un" et entre la majuscule "O" et le chiffre "zéro." Procédez de la même façon pour d'autres notes explicatives.

REFERENCES

Vérifiez le texte afin d'assurer que sont mentionnées toutes les références ou renvois de la liste. Tapez, à doubles interlignes et de la façon prévue (Appendice E) pour le *Journal*, la liste de références. Les noms de journaux sont abrégés suivant la *Biological Abstracts*, mais s'il y a doute, écrivez le nom au long.

VOCABULAIRE

Une liste d'environ cent mots relatifs aux articles sur les pêcheries est disponible au bureau du Directeur de la publication (Appendice F).

APPENDICES

Les appendices de A à F sont disponibles sur demande au bureau du Directeur de la publication.

Reprinted Without Revision **FRB Bulletin 162**

The Sockeye Salmon,
Oncorhynchus nerka

BY R. E. FOERSTER

This Bulletin represents forty years of detailed study of facts and statistics collected during the author's lifetime study of the life history, propagation, and ecology of the sockeye salmon.

It attempts to bring together all that is presently known about sockeye salmon. All studies carried out in the north Pacific sockeye salmon area have been reviewed and their results incorporated in order to present sockeye production under a variety of climatic and environmental conditions, and to assess overall survival, as well as at each stage of the life cycle from egg to adult.

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Journal of the Fisheries Research Board of Canada

Volume 29, No. 7, July 1972

JFRBA29(7)987–1097(1972)

Yearly respiration rate and estimated energy budget for *Sagitta elegans* **D. D. Sameoto** 987–996

Food resource division among northern, marine, demersal fishes **A. V. Tyler** 997–1003

Survival of hatchery-reared rainbow trout (*Salmo gairdneri*) in relation to stamina tunnel ratings **D. L. Horak** 1005–1009

Evidence for a home site and homing of adult yellowtail rockfish, *Sebastes flavidus* **H. R. Carlson and R. E. Haight** 1011–1014

The structure of the attachment organ of Lernaeopodidae (Crustacea: Copepoda) **Z. Kabata and B. Cousens** 1015–1023

Migratory movements of adult sockeye salmon (*Oncorhynchus nerka*) in coastal British Columbia as revealed by ultrasonic tracking **D. M. Madison, R. M. Horrall, A. B. Stasko, and A. D. Hasler** 1025–1033

Mobilization of mercury from sediments into guppies (*Poecilia reticulata*) **D. C. Gillespie** 1035–1041

Vital statistics, biomass, and seasonal production of an unexploited walleye (*Stizostedion vitreum vitreum*) population in West Blue Lake, Manitoba **J. R. M. Kelso and F. J. Ward** 1043–1052

Stability of elemental phosphorus in edible muscle tissue of cod during processing including icing, freezing and thawing, frozen storage, salting, and cooking **W. J. Dyer, D. F. Hiltz, R. G. Ackman, J. Hingley, G. L. Fletcher, and R. F. Addison** 1053–1060

Evidence that Pacific ocean perch (*Sebastes alutus*) in Queen Charlotte Sound form aggregations that have different biological characteristics **D. R. Gunderson** 1061–1070

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A compact recirculation unit for the rearing and maintenance of fish **K. R. Scott and D. C. Gillespie** 1071–1074

Trials with an automated plankton counter **J. Fulton** 1075–1078

Length-weight relationship for pomfret **J. I. Manzer** 1079–1081

Temperature control system for recirculation fish-holding facilities **K. R. Scott** 1082–1083

The first record of *Anguilla rostrata* from Alberta **D. S. Radford** 1084

Dimethyl sulfide as an odor component in Nova Scotia fall mackerel **R. G. Ackman, J. Hingley, and K. T. MacKay** 1085–1088

Subcutaneous hemorrhage in captive sablefish (*Anoplopoma fimbria*): a possible link to mortality **K. N. Thorson** 1089–1090

Downstream movements of white sucker, *Catostomus commersoni*, fry in a brown-water stream of Alberta **H. F. Clifford** 1091–1093

First records of *Bathysaurus mollis* (Pisces: Bathysauridae) from the northeast Pacific Ocean **D. Stein and J. Butler** 1093–1094

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INFORMATION CANADA, OTTAWA, 1972